# BOTANY AS AN EXPERIMENTAL SCIENCE
## IN LABORATORY AND GARDEN

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# BOTANY AS AN EXPERIMENTAL SCIENCE
## IN LABORATORY AND GARDEN

By

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*'In my laboratory I find that water of Lethe which causes that I forget everything but the joy of making experiment.'*

ROBERT BOYLE

*'In a great variety of articles very young persons may be made so far acquainted with everything necessary to be previously known as to engage (which they will do with peculiar alacrity) in pursuits truly original.'*

JOSEPH PRIESTLEY, 1774

PRINTED IN GREAT BRITAIN

# PREFACE

BOTANY at the James Allen's Girls' School for many years has been taught by means of observations and experiments made by the girls themselves in laboratory and garden.

No text-books are used until post-Matriculation work is reached. The girls make their own books, and in them are recorded not only the results of their own experiments, but the results of hundreds of other experiments made during the course of many years.

It is wrong in biological work, as in other branches of science, to generalize from a few facts. Professor Bateson, in the Huxley Centenary number of *Nature* said: 'No one better than Huxley knew that some day the problems of life must be investigated by the methods of physical science, if biological speculation is not to degenerate into a barren debate.'

Of biological science Huxley said: 'The subject-matter is different from that of other sciences, but the methods of all are identical; and these methods are:

1. Observation of facts, including experiments.
2. Comparison and classification, the results of the process being named General Propositions.
3. Deduction.
4. Verification.

Such are the methods of all science whatsoever.'

The time allotted to a lesson at J.A.G.S. is often short, but if the results of experiments are recorded, year after year, there can be accumulated a mass of evidence to which reference can be made. But the reference should not be made until after the members of a class have made their own experiments, and the results have been summarized. In this way there can be a training in scientific method as well as a discovery of facts. There is the training in manipulation, in recording results, in comparing individual results with those obtained by others, and in drawing conclusions from a great number of facts. Any results which differ from the majority are not slurred over, but carefully examined, and possible explanations of the discrepancies are often suggested by the girls themselves.

There are recorded at J.A.G.S. the results of more than 4,000 experiments made to see if pollen is necessary for the formation of fruit. The leaves of more than 350 species have been tested to see if they form starch in the light, and nearly 300 experiments have been made to see if there are pores in leaves, and if so, how they are distributed.

Since the end of last century more importance has been paid at the James Allen's Girls' School to the plant as a living organism than to any other branch of Botany. As a rule the experiments are made by the girls themselves, every girl, either alone, or with a partner, setting up and carrying out the experiments in the laboratory or garden. The only exceptions to this in pre-Matriculation classes are those experiments involving the use of a clinostat or auxanometer, and those showing the respiratory coefficient, anaerobic respiration, and the growth of the root into mercury.

It must be remembered, however, when examining the results of experiments, that these experiments have been made by young inexperienced girls, often with very simple apparatus, and that the time in which to make the experiments is strictly limited, the longest unbroken period being one hour twenty minutes in the School Certificate form and the form below it.

It is impossible for the teacher to verify all results in a short lesson, but it is good for pupils to have responsibility, and to feel the recorded results must depend on their own unaided work. It has been found that the fact that they were helping to build up the school records does appeal to the girls' sense of responsibility.

An objection has been made that this experimental method demands more time than is usually allotted. At Dulwich an unusual amount of time has not been given to Botany. The experiments on pollination, for example, were for many years done by girls who had only one lesson of one hour per week for Botany, and in earlier days still, by classes of forty girls who had only forty minutes. The experiments could only be made on fine days in the summer term, and only part of the time could be given to the experimental work.

Great stress is laid on control experiments, the necessity for which is readily appreciated by the girls, and arouses their critical faculties.

The experimental method of studying Botany has been greatly

helped by the development of Botany Gardens. The gardens have been made gradually in response to the needs of the work. They have become, in many cases, out-of-door laboratories, and the work indoors and out of doors is one. The gardening work itself is voluntary and always has been, but there has never been a lack of volunteers.

In the laboratory, in classes up to and including the School Certificate examination class, the compound microscope is not used, except in studying a green alga, such as *Spirogyra*, and the minute structure of a leaf. Much can be seen with the aid of a good hand-lens, for example, in a piece of wood. The structure in sections of dicotyledonous stems, monocotyledonous stems, lenticels, maize grains, and the mouth parts of insects mounted whole, show well, viewed by a magnifying glass in a special slide holder. Malpighi made his classical discoveries with a simple microscope no better than a half-crown lens of the present day. He was the first to observe the capillaries (1661), he made the earliest anatomical study of an insect (1669), and he demonstrated the nature of the tissues of many animals and plants.

**Records.**

The keeping of records goes on steadily year after year. It was difficult to keep many in the early years (1896–1912) when the gardens were being made and there was no grant, little assistance, and the work had to be done in out-of-school hours.

This book deals with experimental and ecological work. For want of space the accounts of many experiments have been omitted. Other branches of the work, such as morphology and classification, are not included.

With a few exceptions the work described is the work of the pre-Matriculation or School Certificate classes, and not the more advanced work.

H.M.I. Dr. Wager, F.R.S., on the occasion of his last visit of inspection to the James Allen's Girls' School, urged me to write a book giving an account of the work in Botany initiated and developed by me at the school, and include in it records of experiments.

My warmest thanks are due both to Professor V. H. Blackman, F.R.S., Professor of Plant Physiology at the Imperial College of Science, for reading Chapters I to VI (Experiments

in the Laboratory), and to Professor Tansley, F.R.S., Sherardian Professor of Botany, Oxford, for reading Chapters VII to XIV (the Botany Gardens), and for their most valuable suggestions. Also to Professor Tansley for the kindly interest he has taken for years in the Botany Gardens.

I am greatly indebted to Miss Talbot, B.Sc., second Botany Mistress 1912 to 1916, and my successor from 1926 to 1931, the last date up to which the selected records have been taken. Miss Talbot has given constant help throughout the writing of this book.

All the diagrams have been made by 'old girls'. Many more would have liked to help if they had been easy of access. My thanks are due to those who have made the diagrams, and to the great number of 'old girls' without whose help the Botany Gardens could not have been made or maintained.

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EAST FINCHLEY,
N.2.

# CONTENTS

## EXPERIMENTS IN LABORATORY

CHAPTER I

SEEDS AND SEEDLINGS . . . . . . . 1

Experiments to see if seeds will germinate (1) in oxygen, nitrogen, carbon dioxide, (2) at various temperatures. Reserve substances in seeds. Tests for starch, proteins, oils. Action of diastase on starch. Absorption of water by roots, experiments to see if plants can absorb solids, path of water in roots and stems. Growth of seedlings in light and absence of light. Effect of brief light exposure on etiolated seedlings.

CHAPTER II

PHOTOSYNTHESIS . . . . . . . 8

Production of starch. Green leaves from 416 plants of different species tested for starch. Summary of records of experiments. Many results checked by microscopic examination of leaf sections by elder girls. Tests for sugar when no starch found. Conditions necessary for production of starch. Evolution of oxygen. Records of experiments.

CHAPTER III

FOOD OF PLANTS . . . . . . . 16

Constituent elements of plants found by analyses. Essential elements determined by growth of plants in various culture solutions. Generations of plants in culture solutions. Summary of thirty years' experience in water-cultures.

CHAPTER IV

TRANSPIRATION . . . . . . . 22

Liquid tested. Results of experiments on 298 plants to see if pores are present in leaves, and distribution of pores if present. Strips of epidermis under microscope. Minute structure of leaf. Comparison of rates of transpiration from upper and lower surfaces of leaves. Potometer. Comparison of rates of absorption and transpiration. Weight of water lost in transpiration. Rate of transpiration under varying conditions.

RESPIRATION . . . . . . . . 28

Experiments to see what gas is given off, what gas is taken in. Comparison of volumes. Production of heat. Records of experiments. Anaerobic respiration.

CHAPTER V

GROWTH IN PLANTS . . . . . . . 35

Experiments showing distribution of growth in roots and stems. Graphs. Measurement of growth in length.

DIRECTION OF GROWTH . . . . . . 39

Experiments showing influence of presence of water, light, and gravity. Growth of plants on a clinostat. Perception of gravity in a root.

CHAPTER VI

THE SOIL . . . . . . . . . 48

Determination of percentages of (*a*) water lost when soil is air-dried, (*b*) water present in air-dried soil. Mechanical analysis of a soil. Sand and clay compared as to the rate at which (1) water passes up, (2) air passes through. Water capacities of soils. Determination of percentage of humus in various soils. Factors influencing temperature of soils (colour, aspect).

THE BOTANY GARDENS

CHAPTER VII

HISTORY AND ORGANIZATION . . . . . 55

Begun in 1896. No grant for fifteen years. Grant from Board of Education in 1912. Out-of-school voluntary work in a day school. Organization. Use of tools. Visitors from many countries. Subjects of theses in Spain, France, Sweden. School Botany Gardens made elsewhere. Study of animals. Biology gardens.

CHAPTER VIII

POLLINATION EXPERIMENTS . . . . . 60

Experiments (*a*) to find the function of pollen (records of 4,000 experiments), (*b*) to see if self-pollination can take place in various plants (6,000 experiments). Experiments on pollination of primrose. Records of insects seen visiting flowers.

CLIMBING PLANTS . . . . . . . 71

Plants in garden, in class-room, and in laboratory. Experiments showing rates of revolution, influence of thickness of support, and angle of inclination of support. Effect of inversion, growth on a clinostat, and absence of light, on twining stems.

CHAPTER IX

THE LANE . . . . . . . . . 75

Construction. Cost. Study of plants in spring, summer, winter. Tendril climbers. Determination and comparison of degrees of sensitiveness of tendrils. Influence of aspect on time of flowering of plants. Influence of aspect on soil temperatures. Animal life in the Lane. Plants of the J.A.G.S. Lane.

CHAPTER X

THE PONDS . . . . . . . 82

(a) Large pond. Construction. Cost. Water supply. Drainage. Fresh-water marshes.

(b) Smaller pond for little plants crowded out in larger pond. Construction.

List of plants in J.A.G.S. ponds and marshes. Great vegetative reproduction. Plants to avoid.

CONDITIONS UNDER WHICH WATER PLANTS LIVE . 89

Comparison of maximum and minimum temperatures in pond and in air above pond. Study of animal life in ponds.

CHAPTER XI

THE HEATH . . . . . . . 93

Construction. Soil from a Surrey heath. List of plants in J.A.G.S. heath.

THE BOG . . . . . . . 96

Large one in heath. Construction. Peat from Lancashire. Cost. List of plants in J.A.G.S. bogs.

CHAPTER XII

SAND DUNES . . . . . . . 99

Construction. Cost. Colonization of big sand dune by a sand-sedge plant. Vegetative reproduction. List of plants in J.A.G.S. dunes.

SALT MARSHES . . . . . . 101

Soil obtained from two sources. Experiments to ascertain suitable strength of salt solution to be poured on marshes. Quantity of salt solution given in one year. Particulars of research work done by an 'old girl' on J.A.G.S. salt marsh. Material for other research at present time. List of plants in J.A.G.S. salt marshes.

PEBBLE BEACH . . . . . . 104

Pebbles from Brighton. Cost. Imitation of nature in covering up plants with pebbles, and in providing seaweed ('drift') for beach. List of plants in J.A.G.S. pebble beach.

CHAPTER XIII

CORNFIELD . . . . . . . 107

(a) Small and large. (b) Plots of wheat, barley, oats, rye. Weeds of the cornfield.

MEADOW. Dominant grasses. List of plants . . . 108

CHALK BEDS. Construction. List of plants . . . 110

THE WALL. Construction. List of plants . . . 111

VARIATION . . . . . . . . 112

STRUGGLE FOR EXISTENCE . . . . . 112

MENDELIAN EXPERIMENTS . . . . . 113

Actual results in $F_2$ generation compared with theoretical results.

SOIL EXPERIMENTS . . . . . . 115

MANURIAL EXPERIMENTS . . . . . 116

Recent experiments on mustard. Advice from Rothamsted Experimental Station. Plots treated with complete artificial manure, manure lacking phosphate, &c.

CHAPTER XIV

THE WOODS . . . . . . . . 119

Consideration of soil. Damp oakwood the type chosen. 783 oaks (*Quercus robur*) planted. Competition of woodland plants and 'weeds'. Age at which acorns were borne. Birds' nests. Thinning of trees. Plant diseases. Changing conditions in the wood: (*a*) humus content, (*b*) evaporating power of atmosphere, (*c*) light intensity. List of trees, shrubs, and herbs in J.A.G.S. wood.

APPENDIX . . . . . . . . 132

INDEX . . . . . . . . . 137

## NOTE

P. 115, $F_2$ Generation.

*For* Purple flowers *read* Coloured flowers

# LIST OF ILLUSTRATIONS


1. The Ponds in Spring at J.A.G.S. . . . *frontispiece*
2. Growth of bean seedlings of same age in light and absence of light 6
3. Etiolated seedlings exposed to light for various periods . . 7
4. Starch print . . . . . . . . 10
5. Moll's Experiment. Part of leaf in air deprived of carbon dioxide 12
6. Fifteenth generation of pea plants grown in food solution *facing p.* 16
7. Four generations of Aloe plants in food solution . „ 18
8. Cork for food solution jar . . . . . 20
9. Surface view of stomates (magnified) . . . . 24
10. Transverse section of a leaf (magnified) . . . 24
11. A Potometer . . . . . . . . 26
12. Experiment to compare rates of absorption and transpiration . 27
13. Apparatus for seeing if germinating seeds give off carbon dioxide 29
14. Apparatus for seeing if germinating seeds take in oxygen . 30
15. To compare the volume of gases taken in and given off during respiration . . . . . . . . 31
16. Graph showing region of growth in radicle of pea . . 36
17. Graph showing region of growth in hypocotyl of sunflower . 37
18. An Auxanometer . . . . . . . 38
19. Stem of Geranium growing through hole in door towards the light 41
20. Influence of light on direction of growth of hypocotyls . . 41
21. A Clinostat . . . . . . . . 44
22. Influence of gravity on direction of growth of stem of bean seedling 45
23. Influence of gravity on direction of growth of hypocotyl of sunflower . . . . . . . . 46
24. Geranium plant turned upside down . . . . 47
25. Rise of water in sand and clay . . . . . 50
26. Graph representing rise of water in sand and clay . . 51
27. Bracket for tools . . . . . . . 57
28. Pollination experiments in Botany Gardens . . *facing p.* 62
29. Transect of hedge . . . . . . . 76
30. Transect of pond . . . . . . . 84
31. Big pond and back of lane . . . . *facing p.* 86
32. Colonization of sand dune by a single sand-sedge plant . „ 98
33. Pebble beach with distant view of wood . . „ 104
34. The dell and atmometer . . . . „ 128
35. Undergrowth in damp oakwood . . . „ 130

# FOREWORD

LILIAN CLARKE was a really great pioneer in the field of school education. Her thoroughly sound fundamental ideas, her extremely clear and honest mind, her keen enthusiasm, and her indomitable energy and perseverance combined to give her the great success she attained. She trained at least two women who have become distinguished investigators, and there must be scores of others on whom her influence and their experience at Dulwich have left a lifelong mark. The keynotes of her work are common property—that her girls *should do things for themselves*, that they should set up control experiments wherever practicable, that their observations should be exact and properly recorded, and that they should always keep clear the distinction between fact and inference. But it has been given to few teachers to carry these universally accepted precepts into such continuous and effective practice and over so wide a field of the subject.

She met with many difficulties, and for years carried on an uphill fight for money and opportunity for her work. But nothing daunted or discouraged her, and eventually she gained the warm sympathy and active assistance of headmistress, school governors, Board of Education, and school inspectors alike, as well as of many outside people in a position to help. She often came to me for advice, and I was frequently amazed at the boldness of her schemes for new extensions of the work and rather sceptical as to their practicability. Nevertheless, she very rarely failed to carry them to a successful issue. If she made mistakes, she never spared ingenuity or trouble till they were satisfactorily corrected as far as possible. This was particularly true of her creation of a whole series of 'ecological habitats'—lane, pond, bog, sand dune, shingle beach, salt marsh, oakwood—in which could be grown the native plants that naturally inhabit them. As an ecologist I was naturally always urging her to 'let things alone' as much as possible, once a new distinctive habitat was established; but this she could rarely do at all fully, as was natural enough when we remember the largely artificial conditions that have to be maintained in order to get the plants to grow at all and to keep down weeds. Even so, a considerable number of really valuable ecological

observations were accumulated, and there would have been many more if she could have had another ten years at the work. And this quite apart from the educational value to the girls of these pioneer efforts.

In this little book will be found a full record of Miss Clarke's work—her ideas, her plans, her methods, her difficulties, and her successes. It is a story of absorbing interest, and the book is packed with useful practical records and suggestions of all kinds. Miss Clarke was not a practised writer of text-books and she does not always present her material in the way that would be most useful to contemporary teachers who wish to follow her example. Some may regret that she did not write a regular practical handbook for school laboratory and garden work, rather than a record of her own work at Dulwich. But the material is all there and can be extracted and used to great advantage. Laboratory work in plant physiology, which was quite a novelty in secondary schools at the end of last century when Miss Clarke was appointed to her post at the James Allen's Girls' School, has long become a regular part of the curriculum in the better schools and has been considerably developed and perfected, so that some of the author's descriptions of elementary experiments may now seem redundant. But it is all part of her story, and it is a story which is not only inspiring as an example but instructive in numberless details.

I most cordially commend the book to all practical teachers of biology in schools—both girls' and boys'—and to every one interested in school science.

A. G. TANSLEY

OXFORD
*April* 1935.

# EXPERIMENTS IN LABORATORY

## I

## SEEDS AND SEEDLINGS

Conditions necessary for germination. Tests for reserve substances in seeds. Absorption of water. Growth of seedlings in light and absence of light.

IT has been found that the study of seeds and seedlings furnishes a good beginning for work in plant physiology. It leads to the consideration of storage of food reserves, root absorption, transport of raw material, influence of light and gravity on direction of growth, and other subjects of great importance in the life of the plant.

The seed under favourable conditions germinates and forms a seedling. What are the conditions necessary for germination?

1. Seeds germinate in the air, a mixture of gases of which nitrogen and oxygen form the major part. Will they germinate in nitrogen alone? in oxygen alone? Ordinary air contains about three parts per 10,000 of carbon dioxide. Will seeds germinate in carbon dioxide?

At the James Allen's Girls' School it has been found convenient to use respiration retorts ('respiroscopes')[1] for these experiments. Some pea seeds are placed in the bulb end, the retort is filled with water, and a gas is passed into the retort under water, and is allowed to displace all the water except a very small quantity. A well-fitting india-rubber cork is placed in the open end under water; the retort is then taken out and placed with the corked end in a beaker containing water, as an extra precaution to prevent entrance of air. If time permits, this making of the gases and filling of the retorts can be done by the girls themselves, who, at this stage, have a sufficient knowledge of the gases of the atmosphere. In some years the work has been done by the girls in their chemistry lessons. Each gas under consideration is passed into several retorts, and each retort contains several seeds, in order that conclusions may not be drawn from a few results. Some control experiments are made with

[1] A slightly modified form of chemical retorts.

seeds from the same packet, left with a little water in the air of other retorts, which are also corked.

After the experiments have been left for a time, it is seen quite clearly that the seeds have germinated in the control experiments and in oxygen, but not in nitrogen or carbon dioxide.

**2.** Will seeds germinate at all temperatures? It would not be possible to find every temperature at which various seeds germinate, but it is easy to take two extreme temperatures, approximately 0° C. and 100° C., and see if seeds will germinate at those temperatures. It is well to take seeds, such as mustard and cress, that germinate quickly, so that in the one case much ice need not be used, and in the other the water-oven need not be heated for a long period. The seeds are placed on damp sawdust in three crucibles. Ice is put in one crucible, which is surrounded by ice in a basin and put in the coldest place available; another crucible is put in a water-oven; the third is left in the laboratory as a control experiment. Equal quantities of water are given to all. When the seeds in the control experiment germinate, those which have been surrounded by ice have not germinated nor those which have been in the water-oven.

If the crucibles are then left in the laboratory at a normal temperature, the seeds which have been at a very low temperature germinate, but not those which have been in a water-oven at about 100° C.

**3.** It is known to all that water in some form is necessary for the germination of seeds, and pupils can devise their own experiments, or bring forward facts to show that this is the case.

*Summary.* It is therefore found that the germination of seeds depends on (1) the presence of oxygen (as far as experiments have been made), (2) a certain amount of warmth, (3) the presence of water.

**Light and germination.** Recently it has been shown that a number of seeds, as those of the great hairy willow-herb, purple loosestrife, curled dock, and celery-leaved crowfoot, under normal temperature conditions, can only germinate in the light, or have their germination promoted by illumination. A small

number, such as *Phacelia tenacetifolia*, can germinate only in the dark. Temperature, however, seems to play an important part. Those seeds which under normal temperatures only germinate in the light may do so in the dark at a high temperature, and those which normally only germinate in the dark may germinate in the light at a low temperature.[1]

Experiments have been made at J.A.G.S. which showed the advantage of the presence of light on the germination of the seeds of the great hairy willow-herb, and the disadvantage of light on the germination of seeds of *Phacelia tenacetifolia.*

**Reserve substances in seeds.** Many seeds, such as pea, bean, and sunflower, germinate and develop into fairly large seedlings, if they are placed in damp sawdust which contains no nourishment. Examination of the seeds of these plants shows that they contain reserve food material. To determine the nature of these reserves pupils must know the tests for starch, proteins, and oil. Sometimes the members of the class have learnt these tests in their chemistry class. If they have not, the various reactions must be shown in the botany class.

1. Iodine solution (see appendix) is poured on pieces of starch, and a dark blue, almost black, coloration is seen.

2. A little caustic potash is added to some protein, such as white of egg, in a test-tube, enough to cover it, and one drop of copper sulphate added. A mauve colour is seen after a short time.

3. A little oil is placed on blotting-paper, and a greasy stain is produced which is not removed when the paper is dried.

(If seeds are being tested for oil they can be crushed between blotting-paper after the outer coats have been removed, or slices can be cut and heated at a gentle heat in an oven on blotting-paper.)

**Summary of results.** Scarlet runner seeds, broad bean seeds, and pea seeds contain starch in their cotyledons, maize and wheat grains in the endosperm; castor oil seeds, maize grains, and wheat grains contain proteins in the endosperm, sunflower, pea, and bean in the cotyledons; castor oil, sunflower, mustard, and Brazil nut seeds contain oil. (For list of parts of plants other than seeds tested for starch, sugars, proteins, see appendix.)

[1] Skene, *The Biology of Flowering Plants*, 1924.

**Action of diastase on starch.** When the seed germinates active growth takes place and food is needed. Starch is insoluble and indiffusible, therefore, when the reserve food is starch, it must be changed into a soluble substance before it can travel to the parts where it is needed, such as the growing-points of roots and stems. This change is effected by diastase, which is present in germinating starchy seeds, and can be obtained from germinating barley grain, for example.

In order to see the action of diastase on starch a thin starch paste is made (2 grams starch mixed with 20 c.c. cold water and 200 c.c. boiling water added). Some of the starch paste is put into a test-tube A, and some into a test-tube B. A small quantity of diastase is added to the paste in B, and both test-tubes are placed in a water-bath, the temperature of which is about 50° C.

Contents of test-tube A divided into two and tested.

1. Iodine solution gives a dark blue coloration.
2. Heated with Fehling's solution no reddish-brown precipitate seen.

Contents of test-tube B divided into two and tested.

1. Iodine solution gives no blue coloration.
2. Heated with Fehling's solution a reddish-brown precipitate is seen.

The starch in B has been changed into sugar by the action of diastase.

**Absorption of water by the root.** Pea and bean seedlings are placed with the lower parts of the roots in water coloured with eosin. (Red ink can be used.) After a day or two the roots are cut across at different places above the level of the water, and it is seen that the coloured water has been absorbed and has travelled up the root. On placing other seedlings, similar to those above, with the lower parts of the roots in water containing carmine particles (which give a red colour to the water, but which, unlike eosin, are insoluble in it) it is found on cutting the roots across at various levels that the carmine has not entered. Roots do not absorb solids. The same result can be seen very clearly by placing the roots of one plant of narcissus with white flowers in eosin solution, and the roots of another in water coloured with carmine.

Young plants with a good tap-root, such as hedge parsley, also show absorption of coloured water well and are easier for the girls to cut than seedlings.

The above experiments in which the roots of seedlings and plants were in eosin solution showed that the water travelled through the central part of the root—the stele.

**Path of water in the stem.** The path of water coloured by eosin can be seen in the stems of seedlings but not so easily as in older stems.

Laurel twigs are placed in bottles containing eosin solution. At the next lesson it is noticed that the leaves are distinctly coloured, especially the veins, showing that water has travelled up the stem to the leaves. When members of the class cut across the stem above the part which had been immersed in eosin, it appears to be the wood which is coloured. In order to ascertain if this is the case, without using a microscope, other twigs of laurel are taken, and a ring of tissue about ¼ inch in depth is removed from the stem, the cut penetrating as far as the wood. The twigs are then placed in eosin solution with the cut part above the level of liquid, and the leaves become coloured as in the first experiment, the wood in the stem also, but not the pith.

Water ascends through the wood (xylem) of a stem to the leaves.

Transverse sections of the leaves cut by older girls show that the water has passed through the upper part of the vascular bundle—the wood.

**Seedlings in light and absence of light.** Some runner bean seeds of approximately the same size are put in damp sawdust in a number of pots, one in each pot. Some pots are put in a dark cupboard, or preferably a dark-room, and some are kept in the laboratory near a window. The same quantity of water is given at the same time to both sets of seeds, and, when the seeds germinate, to the seedlings. The differences in the development of the seedlings in the light and in the dark are most marked, as shown in a copy of a photograph (Fig. 2).

The seedlings grown in the dark are characterized by:

1. Great length of internodes.
2. Small dimensions of leaf.

3. Weakness of stem.
4. Absence of green colour.

In making the above experiment it is well not to bring the seedlings from the cupboard or dark-room into ordinary light when examining them or watering them, but to use a ruby light.

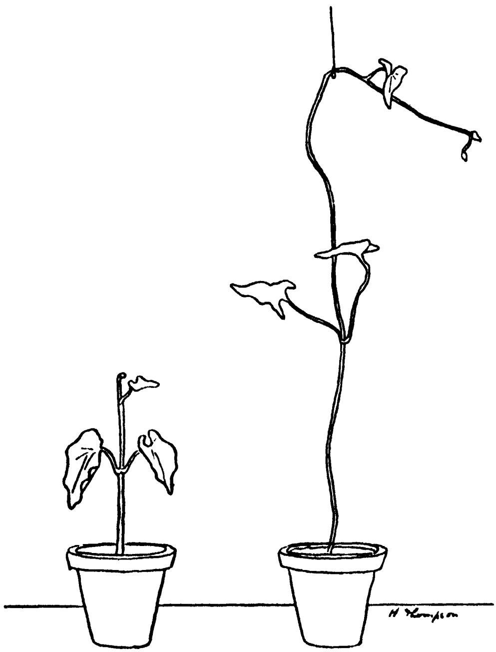


FIG. 2. Growth of Bean seedlings of same age in light and absence of light.

**Exposure of etiolated plants to light for short periods.** It has been shown that exposing etiolated seedlings to the light for even one minute a day makes a difference in their development.[1]

Experiments in light-proof boxes have been carried out at J.A.G.S. by members of the post-matriculation class. It was found that etiolated seedlings of pea exposed to light on consecutive days for one minute showed (1) shorter internodes, (2) signs of lateral leaf development, and (3) a slightly less pronounced plumular hook, than those kept always in the dark.

[1] Priestley, 'Light and Growth', *New Phytologist*, 1925.

Etiolated seedlings were also exposed to light for other lengths of time, namely 30 minutes, and 60 minutes per day, and the

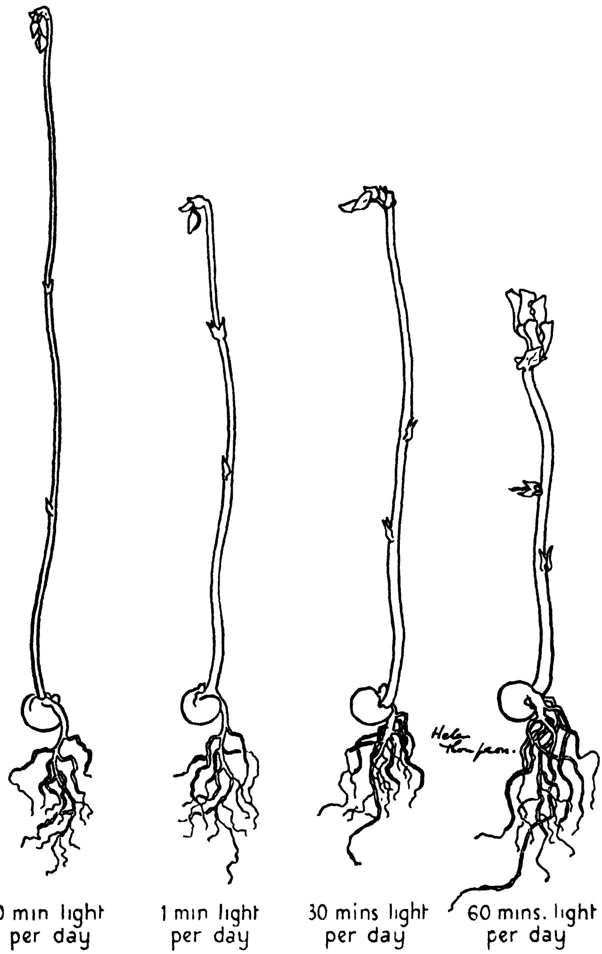



FIG. 3. Etiolated seedlings exposed to light for various periods. Note variation in: (1) length of internode, (2) development of lateral leaf, (3) plumular hook.

effects noted. Those exposed for 60 minutes a day showed a faint green colour.

Additional experiments with seeds and seedlings are described in Chapters III, IV, and V.

## II

## PHOTOSYNTHESIS

STARCH has been found in the reserve organs of many plants. Experiments are made to see if leaves contain starch, and, if so, under what conditions. The girls, while in the laboratory, decide which leaves in the garden, not already tested, they will examine for starch. They pick the leaves, place them in boiling water for ten minutes, and leave them in methylated spirit until the next lesson. If it is wished to decolorize the leaves quickly, after being in boiling water they are placed in a small beaker containing methylated spirit and the beaker is suspended in a larger beaker containing boiling water. (Methylated spirit is highly inflammable.) The decolorized leaves are washed, placed on white dishes, and iodine solution is poured on them. The results of the experiments of all the members of a class are recorded, and a list made of the green leaves in which starch has been found, and of those in which no blue coloration was seen. Then, and not until then, reference is made to the results of experiments of former years, and in this way, generalizations with regard to the presence or absence of starch in leaves of dicotyledons and monocotyledons are being based on a large and increasing number of results.

**Summary of records made in twelve years.**

I. Decolorized leaves treated with iodine. Macroscopic method.

(*a*) The leaves of all dicotyledons picked in the light have been found to contain starch. 388 species.

(*b*) The leaves of 4 monocotyledons picked in the light, and treated as above, showed a decided blue coloration. Arrowhead, black bryony, *Elodea*, wheat.

(*c*) The leaves of 24 monocotyledons picked in the light, and treated as above, showed no blue coloration.

| | |
|---|---|
| Bluebell | Garlic |
| Cotton Grass | Grape Hyacinth |
| Daffodil | Grass, Fescue |
| Day Lily | ,, Meadow |

Grass, Purple Moor
„ Sand Lyme
„ Water
Iris
Lily, Madonna
Lily-of-the-Valley
Montbretia
Narcissus
Onion (very young leaves not taken)
Pondweed, Floating
Reed, Common
Sand Sedge
Snowdrop
Solomon's Seal
Tulip
Woodrush

II. Microscopic method. Sections of some of the above leaves were cut, treated with iodine, and examined under the microscope by elder girls specializing in science. Of the leaves of 24 monocotyledons in which no starch was found by the macroscopic method, no starch was seen in the sections in the mesophyll, or inner tissue of the leaf, but in several starch was found in the guard-cells of the stomates (lily-of-the-valley, iris, snowdrop).

**Possible sources of error.** In noting the results of these experiments on leaves of monocotyledons it must be remembered that the best time for testing the main body of the leaf (the mesophyll) for starch is the late afternoon, and the best time for starch in the guard-cells is early in the morning after dark, and that no botany lesson comes at either of the above times. Also, it has been suggested that in some monocotyledons the capacity for producing starch diminishes as the leaf grows older. In wheat it has been found that in June starch was present in the leaf blades, in July it was only visible at the junction of blade and sheath, and in August no starch was found in leaves or stem though the latter was green.[1]

**Leaves tested for sugar.** The following monocotyledonous leaves which showed no starch in their mesophyll were tested for sugar, and glucose (grape sugar) was found: bluebell, meadow grass, iris, lily-of-the-valley, common reed, Solomon's seal.

**General statement.** Of the dicotyledonous plants 100 per cent. showed dark blue coloration in the leaves with the iodine test; of the monocotyledons only 14 per cent. (excluding those having starch only in guard-cells); of the total number of species tested 93·8 per cent.

[1] Parkin, *Philosophical Transactions. Royal Society*, B, vol. 191, 1899.

In the green leaves of most plants starch is found. What conditions are necessary for its production?

**1. Is starch found in green leaves in the absence of light?** Plants, such as fuchsia and geranium, which had been shown in former experiments to have starch in their leaves, are put in the dark, preferably in an airy place, until by means of the iodine test it is seen that no starch is present in the leaves. Some of the plants are left in the dark-room, or a cupboard, and some are put in a good light in the garden, as control experiments. After a time leaves are picked from both sets of plants, decolorized, and treated with iodine. Hundreds of experiments have shown that if starch-free leaves are left in the dark no starch is afterwards found in them, but that starch is present in the leaves of the control experiments in the light.

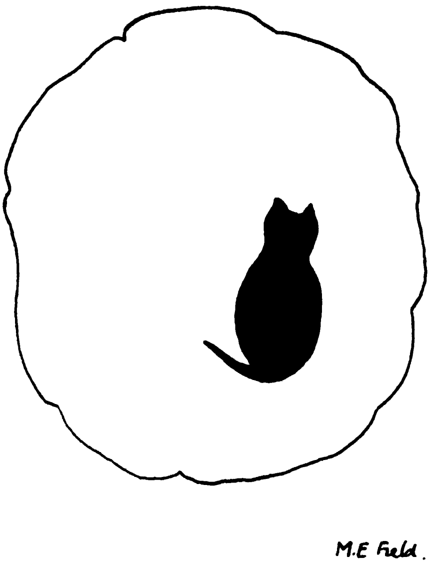


FIG. 4. Starch print.

**Starch prints.**

(*a*) Tin foil, or black paper, in which a stencil has been cut, is bound loosely on the upper surface of a starch-free leaf, still attached to the plant, so that that part will receive no light, but air will not be excluded. (Tin foil is good to use as it has many tiny holes, and therefore does not cut off air from the leaf.) Sometimes the word STARCH is cut, sometimes initials, often other devices, the stencil of a cat being popular with one set of girls.

The plants are put in a good light, and after some hours the leaves are picked, decolorized, and treated with iodine. The word STARCH, or initials, or the outline of a cat, appears in dark blue on the leaf, while the rest of the leaf is yellowish.

Starch is only present in the part which had been exposed to the light.

(*b*) Small's leaf clasps have also been used to obtain starch prints.

**2. Is starch found in green leaves in the absence of carbon dioxide?** It can be shown that starch contains carbon by heating it. The plant is surrounded by air which contains normally about 3 parts per 10,000 of carbon dioxide. Does the plant obtain carbon from this carbon dioxide?

At one time in order to ascertain if this was the case a submerged water plant (*Elodea*), which had no starch in its leaves, was placed in water which had been boiled and contained no carbon dioxide. The control experiment had unboiled water. Both experiments were placed in the light, and later starch was found in the leaves of the control experiment but not in the other.

But it was felt that changes, other than expelling the carbon dioxide, may be made by boiling the water, so Moll's experiment (see Fig. 5) has been used for many years.

A fuchsia, or other suitable plant, is placed in the dark, until its leaves are free from starch, and then the tip of a leaf, while still attached to the plant, is passed into the neck of a wide-mouthed bottle in which is a little caustic potash or lime water. A cork, which has been cut into halves, is fitted into the neck of the bottle, so that the tip of the leaf is in air free from carbon dioxide, the middle part between the cut halves of the cork, and the base outside the cork. The bottle is supported by a clamp and the apparatus is left in a good light. At the next lesson the leaf is picked, decolorized, and treated with iodine. Hundreds of experiments have shown the same results. The part of the leaf that had been outside the cork contains starch, but the parts that had been covered by the cork and in the air devoid of carbon dioxide contain no starch.

(A useful feature of the experiment is that the leaves can be left in methylated spirit, and at any time with the aid of iodine solution the starch-free part of the leaf can be shown.)

Carbon dioxide is taken in by the leaf. Is any gas given off during the process of starch formation? It is better to use water plants, as it is easier to collect any gases that may be given off.

*Elodea* from the pond is used. It is not allowed to be exposed to the air but is transferred from the pond into a basin containing water. It is kept in the dark until it is starch-free (it often takes several days for starch to disappear from a water plant), and then is put into deep beakers containing water.

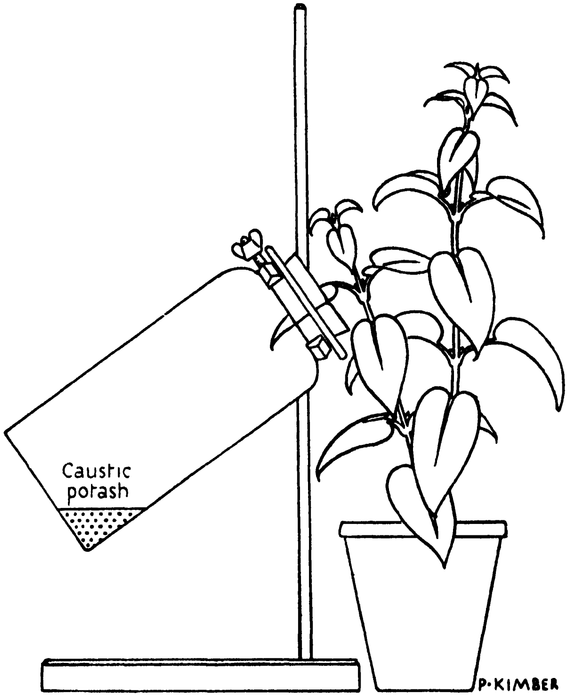



FIG. 5. Moll's Experiment. Part of leaf in air deprived of carbon dioxide.

A large funnel with the stem cut off is put over the *Elodea* in each beaker. A 'boiling-tube' full of water is inverted over the ends of the *Elodea* shoots under the funnel and the beaker placed in a good light. Bubbles arise from the *Elodea* and a gas collects in the tube, and is tested with a glowing splinter. The splinter is rekindled, is blown out, and rekindled again and again.

Every two girls in a large class set up this experiment each year, and in the course of a few years records of many experiments have been obtained. A record of 59 experiments shows that the splinters were rekindled 213 times, an average of more

than 3. Sometimes the splinter is rekindled 6 or 7 times. The gas is evidently rich in oxygen. No oxygen is evolved in the control experiment in which there is no *Elodea*. (The iodine test showed the presence of starch in the *Elodea* leaves.)

The above experiment showing that a green plant in the presence of light and carbon dioxide gives off oxygen, reminds us of the classical experiment of Priestley, the discoverer of oxygen, the bicentenary of whose birth has recently been celebrated (1933). He recorded: 'On the 17th of August, 1771, I put a sprig of mint into a quantity of air in which a wax candle had burned out and found that on the 27th of the same month another candle burned perfectly well in it.'

Experiments, similar to the above (*Elodea* under a funnel in a beaker), are set up in the dark. No oxygen is given off, and no starch is found in the *Elodea*.

Priestley also discovered that green colouring matter and sunlight were necessary for the giving off of the gas (afterwards called oxygen) by the plant.

**3. Is oxygen given off by green plants at low temperatures?** Ice is put in the water in some beakers containing starch-free *Elodea* under a funnel, and renewed inside and outside the funnels, until in the control experiments, where there is no ice, a gas, which can again be shown to be oxygen, has collected in the tubes. No gas collects when the temperature of the water is very low, nor can starch be found in the *Elodea*. Both sets of experiments are kept in a well-lighted place.

**4. Is starch found in leaves in the absence of chlorophyll?** A simple way of answering this question is to use variegated leaves. The leaves of several plants have been used—variegated maple, splashed dead-nettle, variegated pelargonium, and variegated mint, but mint has been found to give the best results. On account of this, many groups of variegated mint have been grown in different parts of the garden, so that during a lesson, a number of girls can go out, pick the leaves, and return to the laboratory in a short time. The leaves are drawn very carefully, the parts which are green in the leaf being shaded in the drawing; the leaves are then decolorized and tested with iodine. On reference to the drawings it is seen that the part which has

become dark blue corresponds to the part which was green, and the part where no starch has been produced to the white part.

**Summary.** It has, therefore, been shown, not in one experiment only in each case, but in hundreds, that for the production of starch the following are necessary: light, presence of carbon dioxide, warmth, and chlorophyll.

**Is starch made in green leaves?** A fuchsia plant, or geranium plant (in the leaves of which starch had previously been found), is put in a dark-room, or cupboard, until the leaves are found free from starch. Several leaves are then picked and put with their stalks in water, some in the light, some in the dark. After a day or two they are all decolorized and tested for starch. It is found that starch has been made by the green leaves in the light.

**Disappearance of starch.** Starch formed in green leaves in the light disappears in the dark. Does it disappear more quickly when the leaf is on the plant, or when it is detached? A plant that had been in the light and contained starch in its leaves is put in the dark room, several leaves are picked from it and left with their petioles in water also in the dark. After 16 hours some more leaves are picked from the plant, and both sets of detached leaves decolorized and treated with iodine. A dark blue colour is seen in the first set of leaves that had been detached, but none in the second. Starch disappears more rapidly from leaves attached to a plant than from those detached.

Starch is insoluble, but as was shown in Chapter I, it can be changed into sugar by diastase. Diastase is present in leaves and can be obtained from them.

**Photosynthesis.** Starch is a carbohydrate. It consists of carbon, hydrogen, and oxygen, the proportion of hydrogen to oxygen being the same as exists in water—two parts of hydrogen to one of oxygen. It has been shown how the plant obtains the carbon. How does it obtain the necessary hydrogen and oxygen? Water taken in by the root-hairs ascends through the root and stem to the leaves. The green plant is able by means

of the energy absorbed from the sun by chlorophyll to make sugar and starch from the carbon dioxide taken in by the leaves, and the water taken in by the root-hairs. The whole process of taking in carbon dioxide, building up of carbohydrates, and evolution of oxygen is called photosynthesis. It is a most important process as the life of the world depends on it. No animals could live if plants did not carry on this process.

'Animals are in the long run always dependent on green plants, they are, one might almost say, parasitic upon plants. Green plants, by the same token, are parasitic upon the sun, they live by stealing energy from his rays.' HALDANE AND HUXLEY.

# III

# FOOD OF PLANTS

Constituent elements of plants found by analyses. Essential elements determined. Plants in culture solutions. Summary of thirty years' experience in water cultures.

IN order to find out what elements are essential as food material to the life of the plant the first step is to ascertain of what elements plants consist. If certain elements are never, or seldom, present, they cannot be necessary. Plants, or parts of plants, are heated in a water-oven to a temperature of about 100° C. during which process water is given off (in this way the percentage of water in various plants can be found—see appendix), and then the dried plants are strongly heated until an ash is produced, and the relation of the weight of the ash to the original weight of the plant can be found (see appendix).

Even if the pupils have only an elementary knowledge of chemistry they can discover while the plants are being strongly heated that carbon dioxide and ammonia are given off. The ash must be analysed by others. But in some classes the pupils will be able to discover for themselves that the ash contains sodium, potassium, a sulphate, and a phosphate (see appendix), so that they know that the following elements are present: hydrogen, oxygen, carbon, nitrogen, sodium, potassium, sulphur, phosphorus. It is usually beyond the power of girls at this stage to analyse the ash completely. In some years it has been given to senior girls, who are specializing in chemistry, and, failing that, analyses, made by an expert, of the ash of various plants have been used. Analyses showed that the metals potassium, calcium, magnesium, sodium, and iron were present in the form of sulphates, phosphates, chlorides, and silicates.

It has therefore been shown that thirteen elements are constantly present in plants: hydrogen, oxygen, carbon, nitrogen, sodium, potassium, sulphur, phosphorus, calcium, magnesium, iron, chlorine, silicon.

In order to find out which of these elements are absolutely necessary, numbers of plants have been grown in food solutions (culture solutions) of varying constituents. If it had not been

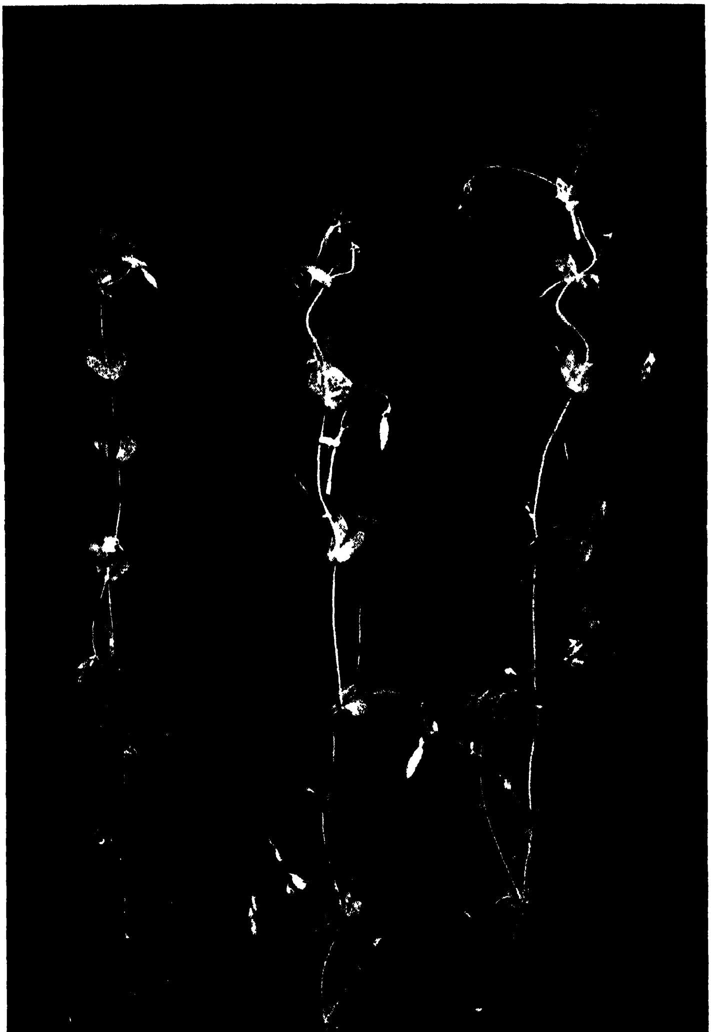


FIG. 6. Pea plants. Fifteenth Generation in Food Solution

The above plants were grown from seeds produced on a single plant the previous year. Two plants were grown from seeds of same pod

ascertained first which elements are constantly present in plants, it would have been an endless task to find out by means of water-cultures which of the ninety-two elements are essential to the life of the plant.

The composition of the solution that has been used for thirty-six years at J.A.G.S. is as follows:

*Sachs' Solution* (*normal solution*)

| | |
|---|---|
| Distilled water | 1 litre |
| Potassium nitrate | 1·0 gm. |
| Sodium chloride | 0·5 „ |
| Magnesium sulphate | 0·5 „ |
| Calcium sulphate | 0·5 „ |
| Calcium phosphate | 0·5 „ |
| Ferric chloride | a trace. |

The above solution has been found most satisfactory. It seems to suit all the plants that have been tried at Dulwich with the exception of beech, and the absence of mycorrhiza in the beech seedling may explain the failure. Schoolgirls are not, as a rule, extremely careful, nor have they much time for these water-culture experiments, but for a period of six years there was not one case of a plant dying in normal food solution, unless it had received some injury before it was put in the solution. Many hundreds of plants have thrived in it, and the following list will give some idea of the variety grown: almond, aloe, birch, bramble, buckwheat, currant, edible chestnut, elder, false acacia, gorse, hawthorn, hazel, holly, horse-chestnut, lupin, maize, oak, orange, pea, peach, poplar, sunflower, sycamore, *Tradescantia*, willow.[1]

One year there were seventy perennials in food solution in the laboratory. It is fascinating to watch the buds opening in the spring, and to note the branching, and the nature of the bud-scales (stipules in oak, leaf bases in sycamore and horse-chestnut). The development of buds can often be seen better in these miniature trees than in the trees out of doors.

Seventeen generations of pea plants have been reared in the above food solution, and have been of intense interest to the girls. The late Francis Darwin when he saw the fourth generation of these plants thought they would degenerate, but they

[1] All the plants were grown from seed except aloe, poplar, willow, and *Tradescantia*.

did not do so. In fact the plants of the seventeenth generation were much finer and bore more fruits and larger fruits than the earliest plants, but we draw no inference from this, as in fairness it ought to be remembered that we became more skilled in looking after the water-cultures, and also the conditions became better.

A piece of aloe stem that had been left in water was found to have developed roots, and was put in food solution. It has lived more than sixteen years, is still living, and is almost embarrassingly big. It has given rise by vegetative reproduction to small plants which have been detached and grown in food solution, and these in their turn have had descendants and there are now in the laboratory four generations of aloes that have never been in soil.

By leaving out one element at a time in a series of culture solutions it has been possible for the girls to find out which of the elements constantly present in the plant are essential to the plant as food material. For example, potassium has been omitted by substituting sodium nitrate for potassium nitrate, nitrogen by substituting potassium sulphate for potassium nitrate,[1] magnesium by omitting magnesium sulphate, sulphur by leaving out magnesium sulphate and calcium sulphate and using magnesium chloride, phosphorus by leaving out calcium phosphate, iron by leaving out ferric chloride, and so on. It is hardly necessary to say that many plants have been grown in each of the abnormal solutions. In this way it has been proved that potassium, nitrogen, magnesium, calcium, sulphur, phosphorus, and iron are necessary to the life of the plant. Other experiments described in Chapter II have shown that carbon is necessary, and that green plants obtain carbon from the carbon dioxide of the air. Of the thirteen elements constantly found in plants ten have been found to be essential: carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, calcium, magnesium, potassium, and iron. Recent research work at Rothamsted has shown that boron is also necessary for some plants.

Numbers of seedlings placed in distilled water have not lived, but when choosing seedlings for these experiments care must be taken to remove the store of food in the cotyledons or else-

[1] Plants in culture solutions lacking nitrogen died, although they were surrounded by the free nitrogen of the air.



(*Phot R A Malby & Co*)

Fig. 7. Four Generations of Aloe plants in Food Solution

where. At J.A.G.S. a pea seedling with cotyledons attached was put in distilled water. True, it became a feeble plant, comparing very unfavourably with pea seedlings in normal culture solution, but it produced a flower and finally a fruit. In making experiments to see what elements are essential it is also necessary to see that any food reserve material is removed, as otherwise the seedlings have a source of food apart from the culture solution.

The equipment and conditions for the above water-culture experiments were certainly not favourable at first. In very early days the girls had only a hanging pair of scales, price two shillings and sixpence, and a number of jam and pickle-jars. For years the same small room was used for chemistry and botany lessons, and the water-culture plants had to be moved off the benches at many chemistry lessons, but still were in the midst of fumes. In spite of these drawbacks the plants thrived. Now they are in a large well-lighted botany laboratory which possesses many balances. It is well to have good conditions and good apparatus for experimental work, but it is a pity to wait for these, and not to see what can be done in spite of difficulties. As has been well said: 'To make the most of simple means is an education in itself.'

It is interesting to note that from the experience gained at school in growing plants in food solutions a former pupil, Dr. Winifred Brenchley, when appointed on the staff of Rothamsted Experimental Station, was able to begin at once that long series of experiments that have been so valuable to farmers and others. At first Dr. Brenchley at Rothamsted used a food solution of the same composition as she had used at school, but after a time substituted 0·5 gm. potassium di-hydrogen phosphate for 0·5 gm. calcium phosphate. A weaker solution was subsequently used for some plants such as peas.

### METHOD OF PROCEDURE AT DULWICH

Gas-jars holding about one litre are used for the smaller plants, and elaborate precautions in preparing the jars advised by some writers have not been taken. It would have been impossible in the short time at the girls' disposal, and with numbers of girls working at the same time, to carry out all the precautions advised.

At Dulwich the solution is boiled before it is used, but at Rothamsted the water is never boiled. It is well, if it can be arranged, not to use water that has been distilled in a copper still. It has been shown that copper compounds usually act as poisons to the higher plants. A concentration of 1 in 1,000,000 of copper sulphate in distilled water stops all growth in barley, but if nutrient salts are present a strength of 1 in 250,000 does not prevent growth though the retarding action is very considerable.[1]

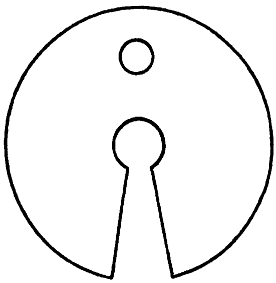


FIG. 8.

A flat cork (shive) is fitted to the jar, and in the middle of the cork a hole is bored, then a wedge is cut out on one side of the cork, and a small hole bored at the other side. Not only seedlings and young plants are grown in these jars, but plants which live for years, develop big root-systems, and have big stems, and it is convenient to be able to take them out easily from the cork when the solutions or corks are changed, or the roots need washing.

Seeds are sown in clean sawdust which has been sterilized and moistened with distilled water. When the seedlings are a convenient size they are put in the solution in the jars. After the stem of the plant has been placed in the centre of the cork, cotton-wool is packed round it, and is also put in the gap in the cork. For some years asbestos wool was used, but cotton-wool has been found to be quite satisfactory.

The disease in seedlings called 'Damping off' is a common cause of failure in water-culture experiments elsewhere.

Darwin and Acton stated that out of fifty-six unsuccessful experiments, where plants died within three weeks, more than thirty were attacked in this way.[2] Great care has been taken at Dulwich that the cotton-wool should not project below the lower surface of the cork, and that neither the cotton-wool nor the lower surface of the cork should become damp. The level of the solution in the jars is usually not less than ¾ inch from the lower surface of the cork, so that when the jar is moved the solution may not wet the cotton-wool or cork.

[1] *Inorganic Plant Poisons and Stimulants*, Brenchley, 1914.
[2] *Physiology of Plants*, Darwin and Acton, 1909.

A glass tube is put through the second hole in the cork, the end going nearly to the bottom of the jar. When the stem of the plant is in position in the cork and surrounded by cotton-wool, and the cork is in the jar, black paper is tied round the jar in order that green algae may not develop. The black paper is always removed when the jar is moved, and the level of the solution watched to see if the cotton-wool or cork become wet. No air is forced into the solution. Some must enter through the loosely packed cotton-wool in the gap, and through the glass tube which dips into the solution, but this tube is introduced mainly on account of its usefulness as a support to the plant.

Frequent change of solution by the girls has not been possible in the limited time at their disposal, only a small part of which can be given to the water-culture experiments, as there are many experiments to be made in other branches of botanical work. Also there are the long holidays, and sometimes no new solution is given for eight weeks. It would not be possible to change the solutions as often as some writers recommend. From the records kept of some of the perennial plants it appears that one plant during 16 years had new solution 127 times, on an average about 8 times a year, another plant during 11 years had new solution 90 times, another during 4 years 31 times, and another during 3 years 23 times.

These water-culture experiments have been a great source of interest to the girls, have afforded a good training in careful attention to detail, and by means of them girls have learnt much concerning the food of plants. The experiments have also aroused much interest in wider circles. An article written years ago, which described, among other experiments, some of the water-culture experiments, brought letters from all parts of England and even from distant lands, asking for advice.

The water-culture experiments at J.A.G.S. were thought to be of such practical importance that one year the organizers of the Bath and West Agricultural Show asked that some of the plants in normal and abnormal food solutions might be brought to the Agricultural Show on Clifton Downs, so that farmers might see them. In spite of great difficulties in taking the plants by cab and by train they were exhibited at Bristol to farmers and others, and were brought back to Dulwich and survived the journeys.

# IV

# TRANSPIRATION. RESPIRATION

## TRANSPIRATION

MEMBERS of the class have often noticed that when plants have been under bell-jars, or ferns in a glass case, moisture has collected on the inside of the glass. Has it come from the soil, or the plant, or from both soil and plant?

Pots containing damp soil are put under dry bell-jars, and a liquid collects on the inside of the bell-jar. In making experiments, therefore, to see if the plant gives off water, it is necessary to cover the soil with india-rubber sheeting, or some other substance through which water cannot pass. But when this has been done, and the pot without a plant is placed under a dry bell-jar, moisture again collects on the inside of the jar. It is, therefore, necessary to cover the pot as well as the soil with india-rubber sheeting.

Experiments are then made on plants, such as geraniums or fuchsias, each pair of girls having a plant. The soil and pot are covered with india-rubber sheeting fitting close to the vaselined stem, the pot is placed on a piece of glass, and a dry bell-jar put over plant and pot. The junction of the glass plate and bell-jar is vaselined, and the experiment left in the light. A control experiment, similar to the last with the exception of having no plant under the bell-jar, is set up in order to see if any liquid condenses from the air. The inside of the bell-jar over the plant becomes misty and then drops of liquid are clearly seen. What is this liquid? It must not be taken for granted that it is water. Various tests are suggested and applied, and in hundreds of experiments the following results have been noted:

1. The liquid is colourless.
2. Blue cobalt chloride paper turns pink in the liquid.
3. Anhydrous copper sulphate (white) becomes blue when placed in the liquid.

The plant in the light has given off water in the form of vapour. In the control experiment no drops of liquid have been seen.

How does this water escape from the plant? Are there pores in the leaves too small to be seen by the naked eye? Each year the girls studying transpiration pick leaves in the garden, preferably those with a petiole, and pressing the petiole firmly between the fingers, put the blades into very hot water. The heat expands the air in the leaf-blades, and bubbles are noticed coming in streams from the leaves. In some leaves, such as black poplar, birch, cow-parsley, laurel, lilac, vine, wood sorrel, yellow dead-nettle, the bubbles are seen on the lower surface only; in others, as floating pondweed, meadow grass, sheep's fescue grass, water crowfoot, on the upper surface only; and in others, as bluebell, clover, daffodil, sunflower, on both surfaces.

After the results of each girl's experiments have been noted, reference is made to results recorded in previous years. In eight years the leaves of 298 species have been tested.

| | | | |
|---|---|---|---|
| Leaves with pores on lower surface only, | 197, | 66·1 | per cent. |
| ,, ,, ,, ,, upper surface only, | 18, | 6·0 | ,, |
| ,, ,, ,, ,, both surfaces, | 83, | 27·85 | ,, |
| | 298 | | |

After the leaves have been treated in the above manner, and the presence of bubbles has indicated on which surface the pores (stomates) are to be found, pieces of the skin (epidermis) are taken from similar leaves with forceps or a razor, mounted in water on slides, and examined under the microscope.[1]

Drawings are made of the guard-cells and other epidermal cells, and also the pores if open. The stomates of the majority of leaves close when surface sections are placed in water, but in some they remain open.

Transverse sections of typical leaves are then placed under microscopes, and each member of the class draws one. It is difficult, as there has been little previous experience in using a microscope, but a knowledge of the minute structure of a leaf seems essential when studying various processes such as transpiration or respiration. Also, it gives some acquaintance, even if only a very slight one, with the wonders revealed by a micro-

[1] Stomates in leaves of floating pondweed, lesser celandine, marsh marigold, and water starwort can be examined without cutting sections, or stripping off the epidermis.

scope. Generally the study of a simpler structure, such as a filament of *Spirogyra* from the pond, precedes the study of a transverse section of a leaf.

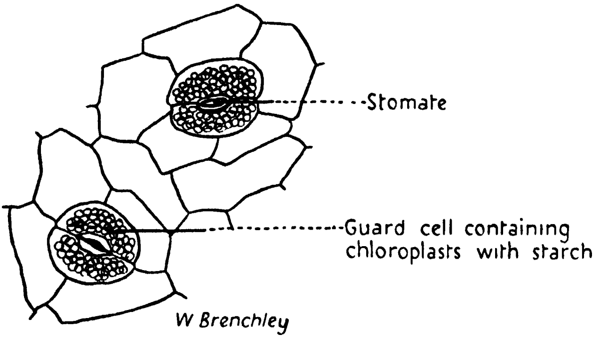



Fig. 9. Surface view of stomates in lower epidermis of laurel leaf (magnified).

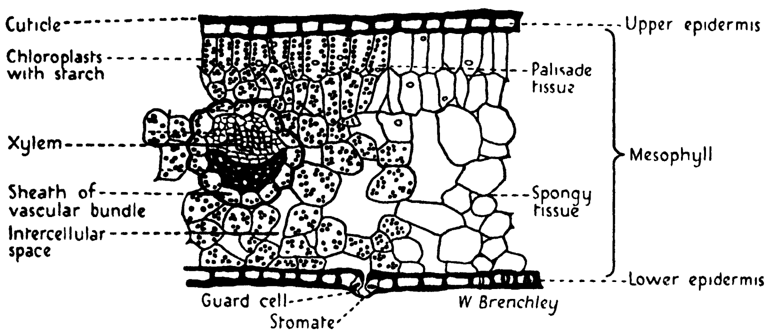



Fig. 10. Transverse section of leaf blade of laurel (magnified).

The majority of leaves have pores on their under surfaces. Is more water given off from that surface in most leaves?

1. Pieces of filter paper, that have been previously dipped in a solution of cobalt chloride, are dried until they are of a deep blue colour, and each leaf, after being carefully wiped, is put with forceps on a piece of cobalt paper resting on a dry glass slide. A second piece of dry cobalt paper is put over the leaf, and then another glass slide. (The slides should project beyond the edges of the paper.) The whole is held together, or secured with india-rubber bands. As a control

experiment a dry piece of cobalt paper is put between two glass slides.

The change of colour from the blue of the dry cobalt paper to pink when water is present is easily seen, and shows when water is being given off by the leaf.

Older girls, specializing in science, often examine the leaves that have been tested in this way and find that the surface from which water has been given off is the surface in which stomates are present.

2. The cut ends of petioles of leaves, such as laurel, are vaselined, and cotton-wool bound round them to prevent water escaping through the petioles. Vaseline is rubbed over the upper surface of some leaves, and over the lower surface of others, and the leaves are suspended in a well-lighted place. After a time the leaves which have only the upper surface vaselined are wilted, while the leaves with only the lower surface vaselined are still fresh. More water is given off from the lower surface of laurel leaves than from the upper. It has already been seen in previous experiments that in laurel leaves the pores (stomates) are only on the lower surface, so again the connexion between the presence of stomates and the giving off of water has been shown.

Leaves from the india-rubber plant are even better than laurel leaves for the above experiment. With the lower surface vaselined the leaves sometimes keep fresh for weeks when those with only the upper surface vaselined are wilted.

From the above experiments it is seen that water is given off in the form of vapour through the stomates—the plant transpires.

The *rate* of transpiration can also be measured. There are different forms of apparatus called potometers. The one shown in Fig. 11 is the one most used at Dulwich, although other forms are also used. It consists of a gas-jar (or bottle with a wide neck) fitted with an india-rubber cork with three holes. Into one hole is inserted a piece of glass tubing of narrow bore, shaped as in the diagram, into another a dropping funnel with a stop-cock, and into the third a shoot. The shoot is cut from a plant, under water, and it is better to do this some time before it is wanted, keep it with the cut end under water, and cut off under water a short length, before placing it in the potometer.

The whole apparatus must be fitted up under water.[1] When the tube, full of water, and the funnel and shoot have been placed in the holes of the cork, the cork is pressed into the jar, the stop-

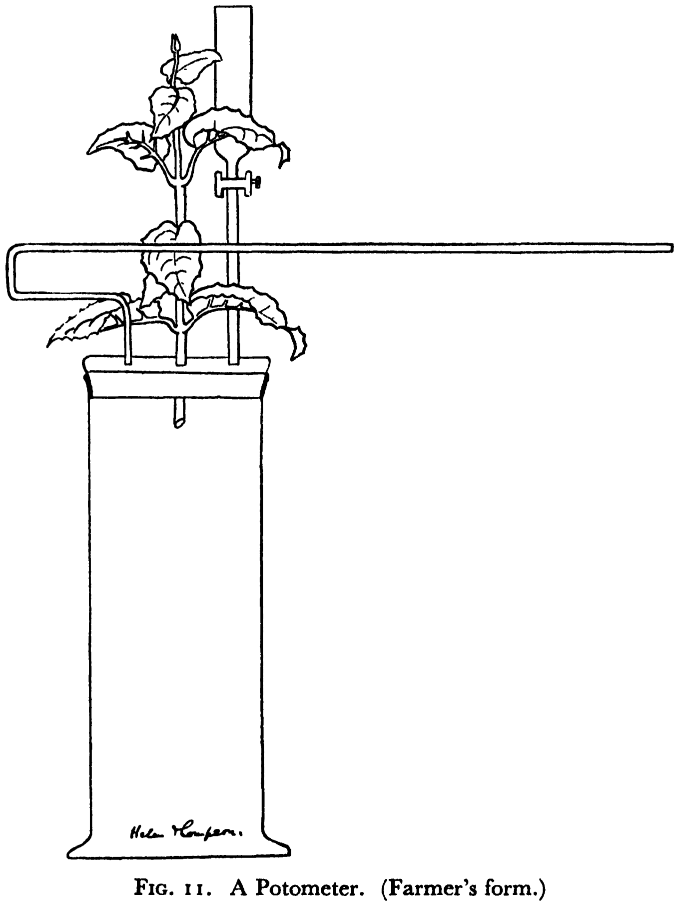


FIG. 11. A Potometer. (Farmer's form.)

cock closed, and the apparatus lifted out of the water. If the stem of the shoot does not fit tightly into the hole, wax must be used.

The apparatus is placed in a good light and the stop-cock turned until the water reaches the open end of the tube. As water, in the form of vapour, is given off by the leaves, water is taken from the jar, and the water in the tube recedes. The

[1] See appendix. Advantage of a deep sink.

advantage of this form of potometer is that when a fresh reading is required the stop-cock can be turned and water again reaches the end of the tube. It is not an expensive piece of apparatus, it is set up by each pair of girls, and many results are recorded.

The volume of water taken up by the shoot in a given time is easily found:

Let $L$ = length of tube along which water has receded.

Let $D$ = internal diameter of tubing, radius ($r$) = $\frac{1}{2}D$.

Volume of water absorbed by shoot = $L \times \pi r^2$.

(In all potometer experiments the average of 2 or 3 readings should be taken as the rate.)

For making quick comparative records capillary tubing is used, a bubble of air introduced, and the time noted for the bubble to travel between two given points.

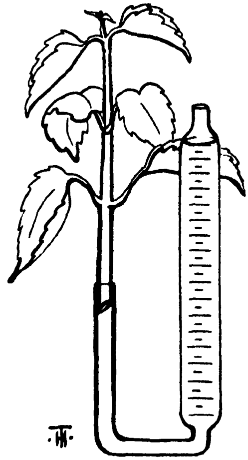


FIG. 12. Experiment to compare rates of absorption and transpiration.

It is the rate of *absorption* that is measured by this apparatus, and it is usually assumed that the rate of absorption is proportional to the rate of transpiration. Experiments are made to see if this is usually the case.

**To compare the rates of absorption and transpiration.**

A J-tube is used with its long arm graduated in cubic centimetres (Fig. 12). A shoot, which has been cut under water, is fitted under water into the short arm. After the tube is taken out of the water and dried, a little oil is poured on the surface of the water in the open end to prevent evaporation. The apparatus is suspended by wire from the arm of a chemical balance, the weight in grams noted, also the volume of water in the tube.

The apparatus is left in a good light, and readings are taken at intervals, showing the volume of water absorbed and the difference in weight. In many experiments at J.A.G.S. the amount absorbed was approximately the same as that transpired (see later), and in using the potometer shown on p. 26 it is taken that this is the case.

But the two amounts are not always the same,[1] and for that reason some prefer to measure transpiration by changes in the weight of a plant. This method also is open to criticism, as it assumes that the change in weight is caused only by loss of water, and does not take into consideration the gain in dry weight due to photosynthesis, and the loss due to respiration. But numerous experiments elsewhere have shown that the error caused by neglecting photosynthesis and respiration is only a fraction of 1 per cent. (See Maximov, *The Plant in Relation to Water.*)

In addition to the potometer experiments the following one is made by all pupils at J.A.G.S., when studying transpiration. A plant in a pot is well watered, the soil and pot covered by rubber sheeting, and the pot then placed on a compression balance in a good light. The weight is noted at intervals. The rate of transpiration is determined by the loss of weight in a given time.

**Rate of transpiration under varying conditions.** By using a potometer under varying conditions the following results have been obtained, an average of several readings in each case being taken after allowing time for adjustment to the new conditions.

1. Transpiration is greater in bright sunlight than in shade, and greater in light than in absence of light.
2. Transpiration is greater in moving air than in still air.
3. Transpiration is greater in dry air than in moist air.
4. Transpiration is greater in warm air than in cold air.

## RESPIRATION

**Do plants take in oxygen and give out carbon dioxide?** To determine whether carbon dioxide is given out experiments are made with (*a*) seeds and colourless seedlings, (*b*) green plants.

The apparatus is arranged as shown in Fig. 13. Fitted Wolff's flasks are used, or jars with rubber corks. The various connexions must be air-tight, the tubes through which air enters the flasks A, B, C, and D should reach nearly to the bottom of the flasks, and the ends of the tubes, through which the air leaves the flasks, should be high in the flasks.

[1] Eberdt showed in one set of experiments that in the day-time transpiration exceeded absorption, and in the evening absorption was greater than transpiration.

When the tap of the aspirator is turned, a current of air is drawn through the apparatus. Caustic soda in flask A absorbs the carbon dioxide of the air, lime water in flask B shows if the air is free from carbon dioxide. After the air, freed from carbon dioxide, has passed through flask C, in which are a number of colourless seedlings and soaked seeds on a wet pad, it passes through flask D, containing lime water.

A control experiment is set up similar to the above, differing only in having no seeds and seedlings. At the beginning of the

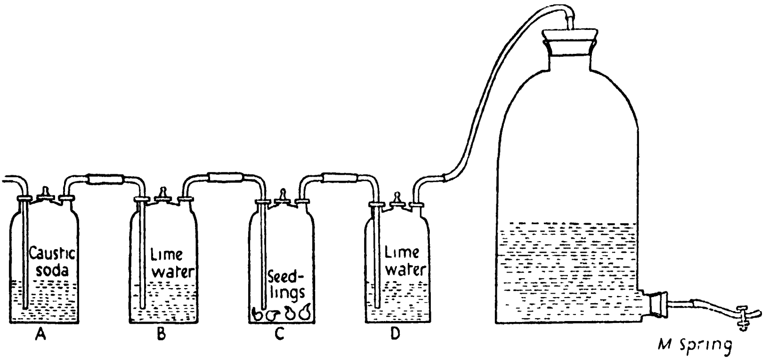



FIG. 13. Apparatus for seeing if carbon dioxide is given off by germinating seeds (or colourless seedlings).

experiment air is drawn through both pieces of apparatus, so that no carbon dioxide shall be present, and then the taps of the aspirators are shut. At the next lesson the taps of the aspirators are turned. Scores of experiments have been made and results recorded.

1. The lime water in B in both sets remains clear.
2. The lime water in D in the experiment which contains seeds and seedlings becomes cloudy ('milky').
3. The lime water in D in the experiment without seeds and seedlings remains clear.

Seeds and colourless seedlings give out carbon dioxide.

(*b*) *A green plant* under a bell-jar fitted with a cork and two tubes is used instead of seeds and colourless seedlings in a Wolff's flask. The bell-jar stands on a piece of glass, and the junction of the bell-jar and plate is smeared with vaseline, so that no air can enter. The same method is used as in the last experiment, but the lime water in flask D does not become milky. What is

the explanation? It has already been seen that green plants in the light take in carbon dioxide, make sugar and starch, and give out oxygen. It is, therefore, necessary, if we wish to see if respiration takes place in green plants, that the plant should not be in the light. A black paper cover is put over the bell-jar, and after a time a current of air is drawn through the apparatus. As in thc previous experiment with seeds and colourless seedlings (1) the lime water in flask B remains clear, (2) the lime water in flask D becomes milky.

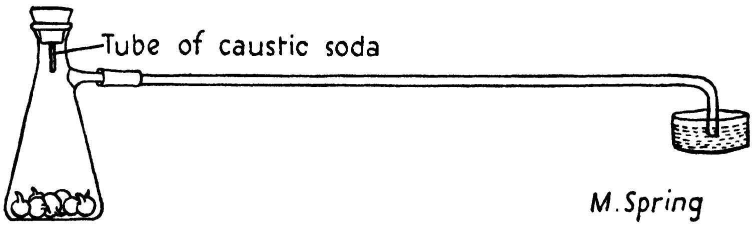



FIG. 14. Apparatus for seeing if germinating seeds take in oxygen.

In a control experiment the apparatus is set up without a green plant. The lime water in D does not become milky.

A green plant in the absence of light gives out carbon dioxide. In the light the carbon dioxide is used in photosynthesis and none leaves the plant.

It has been shown that plants give off carbon dioxide. Do they take in oxygen?

It is not conclusive to see a lighted splinter go out when introduced into a jar containing germinating seeds. This might be caused by the reduction of oxygen, or by the presence of carbon dioxide. Some substance, such as caustic soda or potash, which absorbs carbon dioxide, can be introduced.

A useful piece of apparatus is shown in Fig. 14. The side tube of a filter flask is connected by india-rubber tubing and wire with a long piece of glass tubing the end of which is bent at right angles. Some pea seeds, which have been soaked and are beginning to germinate, are placed on a wet pad in the flask, inside which a short test-tube containing caustic soda is suspended by cotton, and a well-fitting india-rubber cork is put in the flask and holds the cotton in position. The air in the flask is warmed by holding the flask in the hands, and the end of

the glass tube is put in a basin containing mercury. As the air in the flask cools the mercury travels up the tube. When it is stationary the position is marked. An experiment in which there are no seeds is fitted up as a control. After a time it is noticed that the mercury has travelled along the tube in the first experiment, but is nearly in the same place as it was, in the control experiment. A lighted splinter put in the first flask is extinguished, but is not extinguished when put into the flask of the control experiment. Oxygen has been taken in by the seedlings during respiration.

Plants when respiring take in oxygen and produce carbon dioxide.

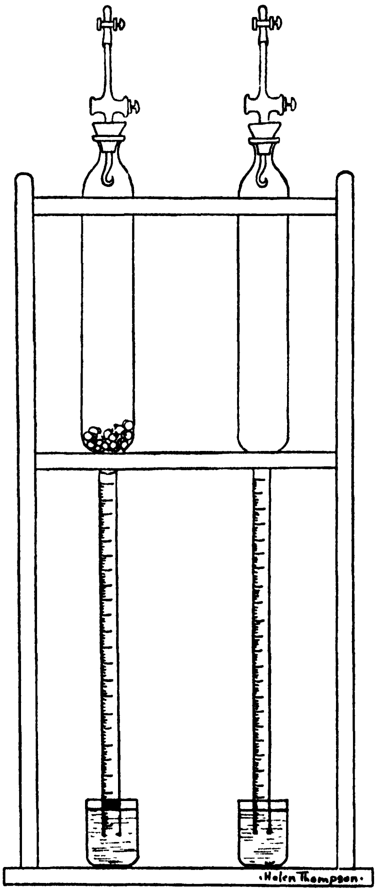



FIG. 15. To compare the volume of gases taken in and given off during respiration.

**To find the value of the respiratory coefficient in pea seeds.** (To compare the volume of carbon dioxide given off and the volume of oxygen taken in during respiration.) The apparatus used is shown in Fig. 15. Damp cotton-wool is put at the bottom of the wide part of one of the tubes and then a few pea seeds in early stages of germination. The other similar piece of apparatus is used as a control experiment. Water is drawn by suction from the beakers until it is at the same level in both graduated tubes, the taps are turned, and clips fastened, so that air cannot enter. The level of the water is read at intervals. Change in the level of the water shows a change in the volume of the air above the water.

The control experiment is arranged in order to see if any difference in the volume of the air is due to change of temperature of the air of the room. One set of records was as follows:

| *Date* | *Time* | *Height of water in apparatus containing pea seeds* | *Height of water in control experiment* |
|---|---|---|---|
| | | cm. | cm. |
| Feb. 2 | 11.30 a.m. | 30·0 | 30·0 |
| | 4 p.m. | 30·5 | 30·5 |
| " 3 | 5 p.m. | 31·0 | 31·0 |
| " 4 | 1.30 p.m. | 31·5 | 31·0 |
| " 5 | 9.45 a.m. | 31·5 | 31·8 |

The results of many experiments at J.A.G.S. show that in the early stages of germination of pea seeds the volume of gas given off equals the volume of gas taken in.

$$\text{The respiratory coefficient } \left(\frac{\text{carbon dioxide}}{\text{oxygen}}\right) = 1.$$

**Respiration in seeds containing oil.** The same apparatus is used as in the last experiment, but, instead of pea seeds, sunflower seeds which contain oil are used. One set of records, as an example, is given below.

| *Date* | *Time* | *Height of water in experiment with sunflower seeds* | *Height of water in control experiment* |
|---|---|---|---|
| | | cm. | cm. |
| May 25 | 10 a.m. | 43·5 | 42·0 |
| " 26 | 9 a.m. | 45·0 | 38·0 |
| | 10.20 a.m. | 43·0 | 37·0 |
| | 11 a.m. | 43·6 | 36·6 |
| | 12 noon | 43·2 | 36·2 |
| | 1.50 p.m. | 42·5 | 35·3 |
| | 4.45 p.m. | 41·5 | 34·1 |
| " 27 | 9 a.m. | 40·7 | 37·6 |

The volume of gas absorbed by germinating sunflower seeds during respiration is greater than the volume of gas given off.

The respiratory coefficient for sunflower seeds

$$\left(\frac{\text{carbon dioxide}}{\text{oxygen}}\right) \text{ is less than } 1.$$

**Is there a change of temperature during the process of respiration?** It is well to take actively respiring parts of plants

such as seeds or flowers. A number of pea seeds which have been soaked in water and are in the early stages of germination are put in a beaker. In a control experiment a beaker of the same size is filled with pea seeds which have been killed by being put in boiling water for a short time. In order that mould or bacteria may not develop on the dead pea seeds a trace, and only a trace, of corrosive sublimate is put in the boiling water in which the seeds are placed. Corrosive sublimate is a deadly poison, and, if preferred, the pea seeds may be placed in a boiling solution of permanganate of potash for a short time. Several thermometers, reading to $\frac{1}{5}$ or $\frac{1}{10}$ degrees, are placed in a beaker containing water, and two which register the same are used, one being put in the midst of the living pea seeds and one in the dead seeds. In each case the bulb of the thermometer is buried in the seeds. A bell-jar is put over each of the beakers, and the stem of the thermometer comes out through the neck of the jar. The space round the thermometers in the neck is packed with cotton-wool.

Readings of temperatures registered by both thermometers are taken at intervals.

RISE OF TEMPERATURE IN RESPIRATION

| *Date* | *Time* | *Temp. of living seeds* | *Temp. of dead seeds* | *Diff.* |
|---|---|---|---|---|
| | | ° C. | ° C. | ° C. |
| March 20 | 9 a.m. | 15·0 | 14·3 | 0·7 |
| ,, ,, | 3 p.m. | 18·6 | 17·0 | 1·6 |
| ,, 21 | 9 a.m. | 17·1 | 16·0 | 1·1 |
| ,, ,, | 4.15 p.m. | 18·7 | 17·4 | 1·3 |
| ,, 22 | 9 a.m. | 16·5 | 15·7 | 0·8 |
| ,, ,, | 3 p.m. | 17·8 | 16·2 | 1·6 |
| ,, ,, | 3.8 p.m. | 17·9 | 16·2 | 1·7 |
| ,, ,, | 4.30 p.m. | 17·2 | 16·3 | 0·9 |

The temperature of the germinating pea seeds is higher than the temperature of the dead seeds.

(More striking results are seen if thermos flasks are used.)

**Can plants respire without oxygen?** Two test-tubes are filled with mercury and inverted in bowls of mercury. (It is well to fit up this experiment on a tray.) The testas of some pea seeds which have been soaked are removed, so that air from

between testa and seed is not introduced, and the seeds are slipped into one of the test-tubes. They rise to the top of the mercury. Black caps are put over the tubes. After a time the mercury is much lower in the test-tube containing the pea seeds. It seems as if some gas has been given out by the germinating pea seeds. A piece of caustic soda, or potash, is put into this tube and rises to the top. The mercury again fills the test-tube, the gas has been absorbed. In the control experiment, the one in which there are no pea seeds, the mercury has not sunk in the tube.

Carbon dioxide has been given out by the germinating pea seeds, although no oxygen has been absorbed. This process is called anaerobic, or intra-molecular, respiration, and can only go on for a time.

**Summary.** During respiration oxygen is taken in and carbon dioxide produced, but this is not the whole of the process. The rise of temperature during respiration shows that energy has been liberated. Substances, such as carbohydrates, undergo combustion in the presence of oxygen, carbon dioxide is formed, and energy released. As a rule the volumes of gas taken in and given out are equal. Anaerobic, or intra-molecular, respiration can go on for a time in the absence of oxygen.

## V

## GROWTH IN PLANTS. DIRECTION OF GROWTH

IS growth in length in plants restricted to definite regions in roots and stems?

**The root.** Well-developed, straight radicles, about an inch long, of runner beans, which have been growing in damp sawdust, are dried with blotting-paper, and on them horizontal lines, one millimetre apart, are marked in Indian ink, *beginning at the tip*. The seedlings are pinned through the cotyledons on to a piece of sheet cork with the roots pointing vertically downwards, the piece of cork is wedged into a jar containing a little water, and a stopper or cork put in the jar. The jars are put in the dark until the next lesson.

It is then seen that there are no longer equal distances between the marks. The maximum growth in length of the root has taken place a little above the tip. At the tip itself there is little or no difference in the interval between two successive marks, but for a short distance the intervals become wider until the maximum is reached; after that there is a gradual decline in the length of the interval until near the cotyledons the interval only measures the original millimetre. (See Fig. 16.)

**The stem.** Horizontal lines in Indian ink are marked on the plumules of runner beans, and pea seedlings, and the hypocotyls of sunflower, in every case beginning at the tip.

Again, after a short time, the lengths of the intervals are found to be unequal. The region of maximum growth is some distance below the tip, and the lengths of the intervals gradually decrease on each side. (See Fig. 17.)

On comparing the regions of elongation in the root and stem of a runner bean it is seen that it extends farther in the stem than in the root. In the stems of some plants regions which are several centimetres from the tip grow in length.

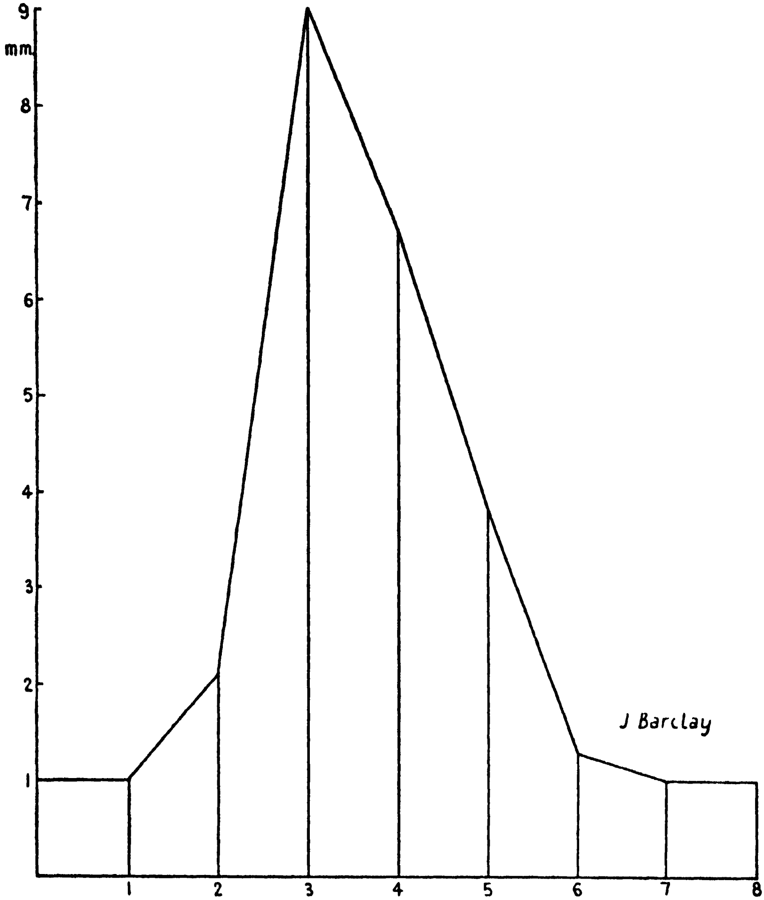



FIG. 16. Graph showing region of growth in radicle of Pea. Average result of 9 experiments. Lengths of verticals represent distances after 3 days between marks originally 1 mm. apart.

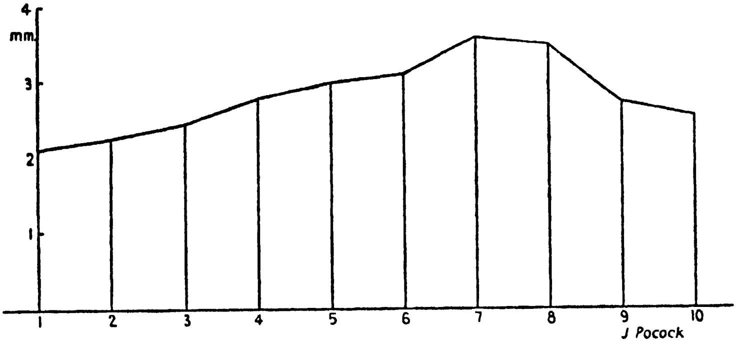



FIG. 17. Graph showing region of growth in hypocotyl of Sunflower. Average result of 10 experiments. Lengths of verticals represent distances after 3 days between marks originally 1 mm. apart.

The results of nine experiments made by members of a class, showing which parts of sunflower hypocotyls grow most quickly, are seen in the following table.

CLASS RESULTS. THE GROWING REGION IN THE HYPOCOTYL OF SUNFLOWER

| *Spaces between marks* | *1–2* | *2–3* | *3–4* | *4–5* | *5–6* | *6–7* | *7–8* | *8–9* | *9–10* |
|---|---|---|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| | 1·5 | 1·5 | 2 | 2 | 2 | 2 | 2·5 | 1·5 | 1 |
| | 1·5 | 1·5 | 2 | 2 | 2 | 1·5 | 1·5 | 1 | 1 |
| | 1 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 1 |
| | 1 | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 1 |
| | 1·5 | 2 | 2 | 2 | 2 | 2 | 1·5 | 1·5 | 1 |
| | 1·5 | 2 | 2 | 2 | 2 | 1·5 | 1 | 1 | 1 |
| | 2 | 2 | 1·5 | 1·5 | 2 | 1·5 | 1·5 | 1·5 | 1·5 |
| | 2 | 2 | 1·5 | 1·5 | 2 | 1·5 | 1·5 | 1·5 | 1 |
| | 2 | 2 | 3 | 3 | 3 | 2·5 | 2 | 2 | 1·5 |
| Average | 1·5 | 1·9 | 2·1 | 2·1 | 2·1 | 1·9 | 1·7 | 1·5 | 1·1 |

Note. Lines originally 1 millimetre apart.

**Accurate measurement of growth in length.**[1] An instrument known as an auxanometer (Fig. 18) is used to make accurate measurements of the growth in length of an organ during a stated period. There are many forms. At Dulwich the same instrument has been in use for nearly thirty years, and a great number of experiments have been made with it. Care

[1] See also Darwin and Acton, *Physiology of Plants*, 1909.

is required in setting it up. The tip of the stem of a plant in a pot is fastened by thread to a hook at one end of the lever. Attached to the other end of the lever is a triangular piece of stiff glazed paper, bent so that its pointed tip can 'write' on the blackened paper (see appendix) which surrounds the drum.

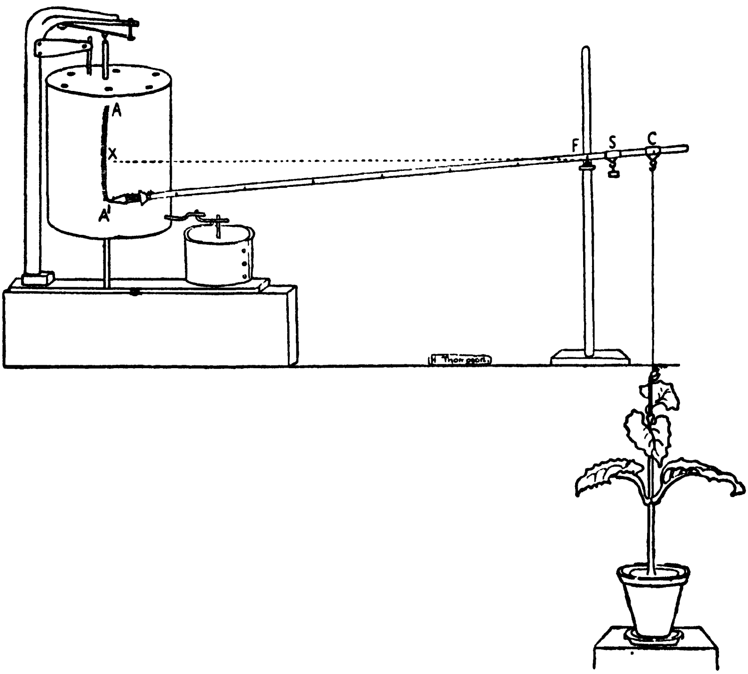



FIG. 18. An auxanometer (Farmer's).

Fulcrum (F) opposite middle of drum (X). A'F = 7 FC. S, sliding clip (with hook for light weight if needed), to bring tip of lever at start of experiment to position A (without undue tension of thread).

The lever is balanced on a knife-edge, and it should be arranged that the arm which is nearer the drum is several times the length of the arm which is nearer the plant. Projecting from the base of the drum is a piece of metal which is struck every hour, or half-hour, or quarter-hour by the minute hand of the clock, and thus the drum, which can revolve a short way, is carried a little way with it. An arrangement is present above the drum which brings it back to its original position after it has revolved.

As the stem grows in length, the end of the lever connected

with the stem is raised, and the other end lowered, and the tongue, which rests against the blackened surface of the drum, makes a longitudinal mark. At regular intervals (one hour is a convenient period) the 'hand' of the clock hits the projection on the drum and causes it to revolve; when the drum swings back a short horizontal mark is made. The vertical distance between two successive horizontal lines gives the apparent growth in length of the stem in one hour, but is really as many times the actual growth in length as one arm of the lever is longer than the other.

By means of the auxanometer it can be shown that the rate of growth in length is greater in the absence of light than in its presence, provided that the temperature is approximately the same. The influence of temperature on the rate of growth can also be demonstrated.

## DIRECTION OF GROWTH

### 1. Influence of water.

**The root.** Occasionally when the flap in the pond (see p. 82) has been lifted the water has not run away, and a wet place in the grass, sometimes at a distance, has shown that water cannot pass in the pipe underneath. On investigation it has been found that the drain pipes no longer fit against each other, and are crowded with roots. The water seems to attract the roots.

In the laboratory experiments have been made to see if growth curvatures in roots can be produced by the presence of water. Damp sawdust is put in two sieves to the depth of about half an inch and cress seeds are scattered on the surface. The sieves are placed in the dark, at an angle of 45°, in basins containing some water. When the seeds germinate, and the roots are growing downwards towards the bottom of the basins, the water is emptied from one basin and left in the other. The sawdust in both sieves is kept moist. The roots of the seedlings over water continue to grow downwards, but the roots of the seedlings which have no water below them grow towards the damp sawdust. On one side of these roots the damp sawdust is much nearer than on the other, owing to the inclination of the sieve, and the roots grow towards this part.

The presence of water has an influence on the direction of growth of roots.

**2. Influence of light.**

(*a*) **The stem.** It is known to most people that if plants are placed near a window, or other place illuminated on one side only, their stems grow towards the light.

1. In the laboratory a hole has been cut in the door of a cupboard, and a plant, such as a geranium or fuchsia, with a well-developed straight main stem, is put in the cupboard. The stem grows out through the hole towards the light and the leaves have their flat surfaces at right angles to the direction of the rays of light (Fig. 19). If the plant were put on the floor of the cupboard, or on blocks on the floor, each time the door was opened the stem and leaves would be dragged back through the hole, so a small shelf has been attached to the door itself, and the position of the stem and leaves is unaltered when the door is opened.

2. Other experiments showing the influence of light on the direction of growth of stems are made on mustard seedlings (Fig. 20). Coarse muslin is tied loosely over the top of a number of gas-jars, so that it sags a little. Water is poured in the jars until it just touches the muslin, mustard seeds are put on the muslin, and the jars placed in the windows. The seeds soon germinate, and first the hypocotyls and then the plumules grow towards the source of light. If the jars are turned through 180° the young parts of the stems again grow towards the light, and if this is repeated the stems have a sinuous appearance. In the control experiments black paper is tied all the way round the jars and projects well above the top of them. The stems grow straight up, and the roots downwards.

(*b*) **The root.** If from the beginning of the experiment black paper is tied round the jars, except for a narrow longitudinal chink, and the jars are placed in the windows with the chink facing the light, it can be seen that the roots of the mustard plants grow away from the light.

If when the jars are turned through 180° the position of the black paper is altered, so that the chink again faces the light, the roots of the mustard again grow away from the light.

But other experiments have shown that in many plants light does not have a directive influence on the growth of roots.

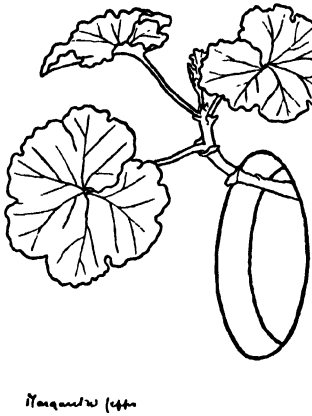


FIG. 19. Stem of Geranium plant growing through hole in cupboard door towards the light.

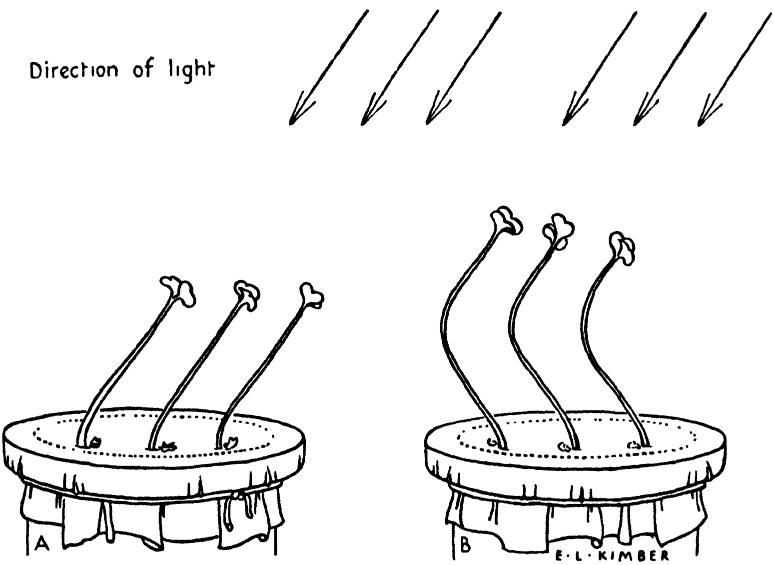



FIG. 20. Influence of light on direction of growth of hypocotyls of mustard B. Jar turned through 180° from its first position (A).

**Region of light perception.** Is there in some plants a part which is particularly sensitive to the stimulus of light? Some Italian Millet (*Setaria*) seeds are sown in a pot, and while the leaves of the seedlings are still within the plumular sheath, the tips of some are covered by caps made by twisting tinfoil round the point of a pin. The pot is put in a box with light coming through a narrow slit from one direction only.

At the next lesson it is seen that the uncovered coleoptiles have bent towards the light, but not those covered at the tip. The upper part of the coleoptile of Italian Millet is therefore the perceptive part, or at least much more sensitive than the lower. The part which actually curves is at a little distance below the tip.

**Recent experiments. Influence of light on direction of growth.** Experiments have been made by a number of observers on the tips of coleoptiles of various members of the family Gramineae. In 1919 Paal described experiments in which the tips of the coleoptiles of a grass (*Coix lacrima*), after exposure to one-sided illumination, were cut off and put eccentrically on the stumps of other coleoptiles, which had not been exposed to one-sided illumination, with the result that the coleoptiles curved away from the side covered by the tip. It was concluded that a substance formed in the tip had diffused into the stump and accelerated cell growth in the elongating zone.

F. W. Went first definitely proved (1926) that a growth-accelerating substance was produced in the tips of coleoptiles. He cut off the tips of some coleoptiles of oat seedlings and placed them for an hour on a thin block of agar, a substance something like gelatine. The block was then cut into small pieces of equal size and each piece stuck on one side of the cut surface of a coleoptile which had just been decapitated. The coleoptiles so treated curved away from the side covered by the agar.[1]

The name 'auxin' has been given to this growth-accelerating substance, and it has been shown that when there is one-sided illumination of the coleoptile there is less auxin on the side towards the light than on the other. Curvature towards the illuminated side is the result.

[1] R. Snow, 'Growth Regulators in Plants', *New Phytologist*, 1932.

**3. Influence of gravity.**

(*a*) **The root.** The main root of a plant is generally observed to be growing vertically downwards. Experiments are made to try to find the cause of this downward growth.

1. Is it the weight of the root? Corks, cleft at the base, are wedged on to the edge of a basin containing mercury, and young bean and pea seedlings, with straight radicles, are pinned on the corks so that the radicles are horizontal, and supported by the mercury. Strips of blotting-paper, with one end in a basin of water, are laid along the seedlings to supply the roots with water. It is well to have the experiment on a tray in case mercury should be spilt. The experiments are put in the dark, and bell-jars placed over them. After a short time it is seen that the roots have grown down into the mercury. The weight of the mercury displaced is greater than the weight of the root, so the downward growth of the root is not due to its weight.

2. Other experiments are then made. Young runner bean seedlings with straight radicles, about one to one and a half inches long, are pinned on a sheet of cork. Some of the roots point vertically upwards, some are horizontal, and some are in other positions. The piece of cork is fitted into a wide-mouthed stoppered jar, and the jar put in the dark so that light shall have no influence on the direction of growth, but moisture must be supplied or the roots will die. If water is put in the jar, and the roots grow downwards, it might be concluded that the presence of water at the bottom of the jar has caused the downward growth of the roots, so a piece of wet cotton-wool is stretched across the top of the jar and kept in position by the lid. The air in the jar is thus kept moist.

In a day or so all the roots are growing vertically downwards. The direction of growth has not been influenced by light, nor by the presence of water. It seems as if gravity has an influence on the direction of growth of roots.

3. A piece of apparatus called a clinostat is used. It is so constructed that a plant can be rotated slowly in a vertical or horizontal plane. If a plant, or seedling, with its root and stem horizontal, is rotated in a vertical plane, all sides of the root and stem in succession are subjected to the influence of gravity, so the influence of gravity is equally distributed. A form of

clinostat used for many years at Dulwich is shown in Fig. 21. In experiment after experiment it is seen that when the plant or seedling is rotated slowly (four times in the hour) in a vertical plane in the dark, there is no curvature of the root, although in a control experiment near the clinostat, in which the root is horizontal, downward curvature does take place.[1]

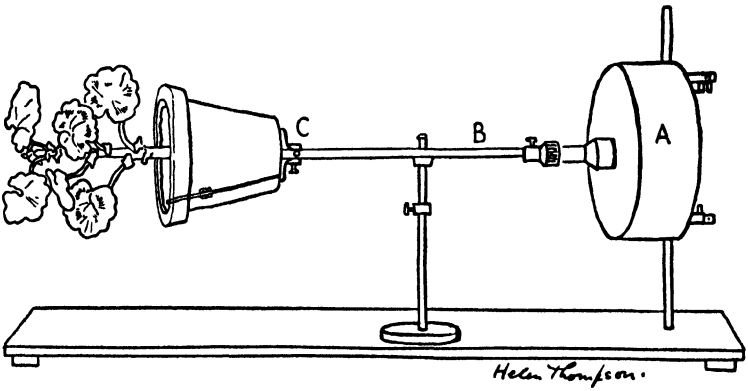



FIG. 21. A clinostat.

The works of a powerful eight-day clock, geared to a revolution in 15 minutes, are encased in a drum (A). A spindle rod (B) is attached to the drum and rests on a vertical support. At the end of the rod is a disk (C) with screw rods by means of which a plant can be attached to the disk. The weight of the plant must be centred.

**Perception of gravity in a root.** Experiments similar to those made by Charles Darwin[2] are made by every member of the class. The extreme tips of the roots of some young pea seedlings are cut off and the seedlings pinned, as in Experiment (2), on a sheet of cork with their roots pointing in various directions, but not vertically downwards. Other seedlings, with their tips intact and pointing in similar directions, are placed on the same sheet of cork, and the cork wedged into a jar, which then has a stopper put in it, and is placed in the dark. The roots without tips usually grow, but do not grow downwards until new tips have been developed. The roots with tips, as in Experiment (2), grow vertically downwards. The region of perception of gravity in a root seems to be the tip.

[1] The clinostat can also be used to secure equal illumination on all sides when a plant is rotated in a horizontal plane.

[2] Ciesielski was the originator.

If, however, the seedlings are put with the roots horizontal for a short time, and then the tips are cut off, the roots do grow downwards.

Experiments have also shown that if horizontal lines are marked in Indian ink on the roots and stems of seedlings, at

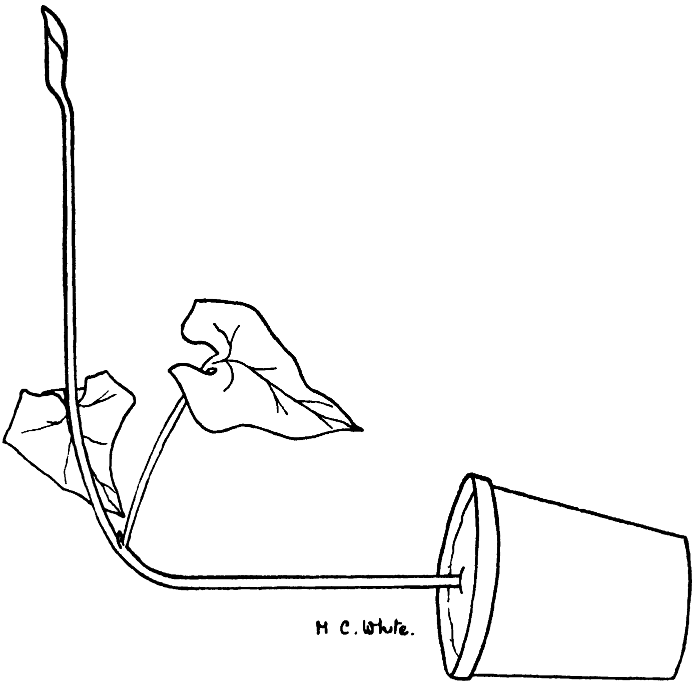



FIG. 22. Influence of gravity on the direction of growth of stems. Bean seedling after it had been placed in the dark with its stem horizontal.

equal intervals, and the roots and stems placed horizontally, the region of maximum elongation is the region of curvature.

Recent work on the perception of gravity in roots has shown that if the tip from a root of maize, which has been in a horizontal position, is stuck on the stump of a decapitated root, which has been vertical, curvature follows. The curvature is stated to be caused by a redistribution of a growth-regulating substance in the tip.[1] Other experiments have been made showing that the growth-regulating substance, which is growth-

[1] Keeble, Nelson, and Snow, *Proc. Roy. Soc.*, 1929.

retarding, accumulates to a greater extent in the lower half of the tip of a root placed horizontally than in the upper, and curvature follows.[1]

(*b*) **The stem.** 1. Bean seedlings are placed in the dark with the stems horizontal. Fig. 22 shows a drawing of the stem of a

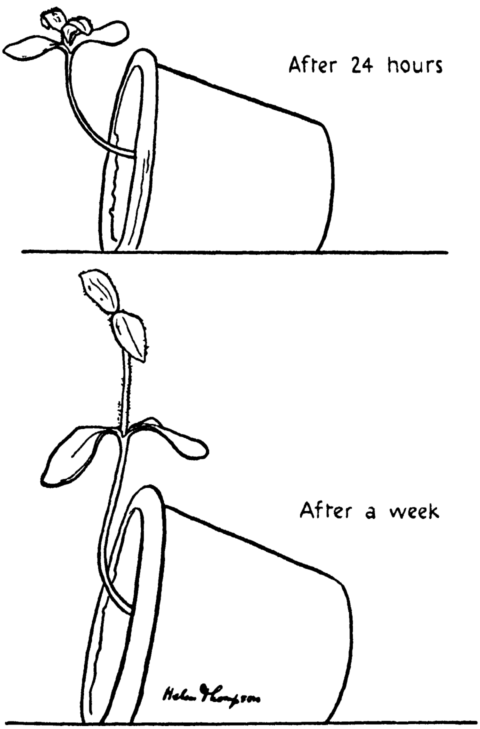



FIG. 23. Influence of gravity on the direction of growth of hypocotyls. Sunflower seedling 24 hours, and 7 days, after it had been placed in the dark with its hypocotyl horizontal.

bean seedling growing vertically upwards after the seedling has been placed with the stem horizontal, and Fig. 23 shows two drawings of the hypocotyl of a sunflower, 24 hours and also 7 days after it was horizontal.

2. Geranium and fuchsia plants are turned upside down on a tripod, the top of the pot first being covered to prevent earth

[1] Hawker, *New Phytologist* Dec. 1932.

falling out. For some years pieces of cardboard were used, but these became sodden when the plant was watered and plates of tin were cut with a slit on one side, and a hole in the middle for the stem. These cost very little and are used time after time.

It can be seen quite clearly from the diagram that the young parts of the stems have grown away from the centre of the earth

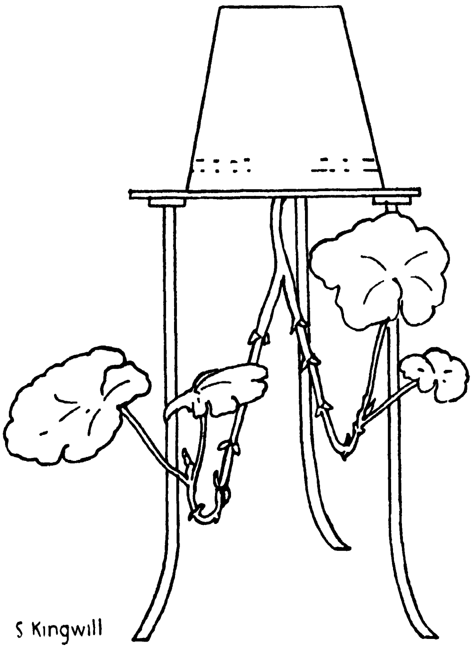



FIG. 24. Influence of gravity on the direction of growth of stems. Geranium plant turned upside down.

and that the upper surfaces of the leaves are again facing upwards. Sometimes the inverted plants are placed in the dark, sometimes in the garden in a place where, as far as possible, they are equally illuminated on all sides.

3. *The Clinostat.* Plants have been placed in the clinostat with the stem horizontal, and rotated for days in a vertical plane in the dark. No upward curvature of the stem has taken place, although, in a control experiment near the clinostat, the stem of a plant which had been horizontal has grown upwards.

## VI

## THE SOIL

THE experiments described in this chapter are some of the soil experiments made in the J.A.G.S. laboratory, many of them each year for more than twenty years. Some of the soil experiments in the garden were made much earlier. (See Chapter XIII.)

**1. To find the percentage of water lost when soil is air-dried.** Samples of soil are taken from various botany gardens, such as the wood, the pollination beds, and the sand dune, and each pair of girls weighs out a small quantity, say 100 gm., spreads it out, and leaves it exposed to the air in the laboratory. At the next lesson the soil is re-weighed, and the process repeated until the weight is constant.

**2. To find the percentage of water still present in air-dried soil.** Some of the soil that had been air-dried in the previous experiment is put in a weighed evaporating dish, the weight found, and the dish placed in a water-oven (temperature approximately 100° C.). After a time the dish and soil are weighed again, then replaced in the oven, and the process repeated until the weight is constant.

The percentage of water still present in the air-dried soils varies in the clay soils from the pollination beds, the soil from the wood, and the soil from the sand dune.

(The various oven-dried soils may be kept in stoppered jars and used in other experiments.)

**3. To make a mechanical analysis of a soil.**[1] Soil is brought from the botany gardens and is air-dried. Some is shaken on a sieve the meshes of which measure 1 millimetre. Stones, gravel, and part of the organic remains (humus) are left on the sieve.

Five grams of the soil which passes through is put in a beaker (A), and water is added to a height of three inches. The level of the water is marked, the soil and water are stirred up and then

[1] See Farmer, *The Book of Nature Study*, vol. v, The Caxton Publishing Company.

allowed to settle for a minute. The water, which contains fine particles of soil, is then poured into another beaker (B). This process is repeated until the water in A is practically clear at the end of a minute. The turbid water in B, which has been poured from beaker A, is allowed to stand for a few days, then the water is poured off, and the sediment oven-dried. This sediment is silt and clay.

The sediment at the bottom of beaker A is also oven-dried, and is then shaken in a sieve the meshes of which measure ¼ millimetre. Fine sand comes through and coarse sand is left.

The soil is thus shown to consist of humus, stones, gravel, coarse sand, fine sand, silt, and clay.

RESULT OF ONE EXPERIMENT IN A TABULAR FORM

| | | | *Weight* | *Percentage* | *Soil* |
|---|---|---|---|---|---|
| Part which did not pass through 1 mm. sieve. | | | | | Humus, stones, gravel. |
| Part which did pass through 1 mm. sieve. | Part which settled in 1 minute. | Part which did not pass through fine sieve. | 0·47 gm. | 9·4 | Coarse sand. |
| | | Part which did pass through fine sieve. | 3·6 gm. | 72·0 | Fine sand. |
| | Part which did not settle in 1 minute. | | 0·93 gm. (by calculation) | 18·6 | Silt and clay. |

In a mechanical analysis made of another soil the results were as follows:

5 gm. taken after soil had been air-dried and stones and gravel together with some humus removed

| | |
|---|---|
| Coarse sand . . . | 26·4 per cent. |
| Fine sand . . . | 53·2 ,, |
| Silt and clay . . | 20·4 ,, |

**To compare the power of sand and clay to lift water.** Pieces of wide combustion tubing, 18 to 20 inches long, are used, and fine muslin is tied over one end of each. One tube is filled with oven-dried sand, and the other with oven-dried powdered clay. (It is well to keep tapping the tubes when they are

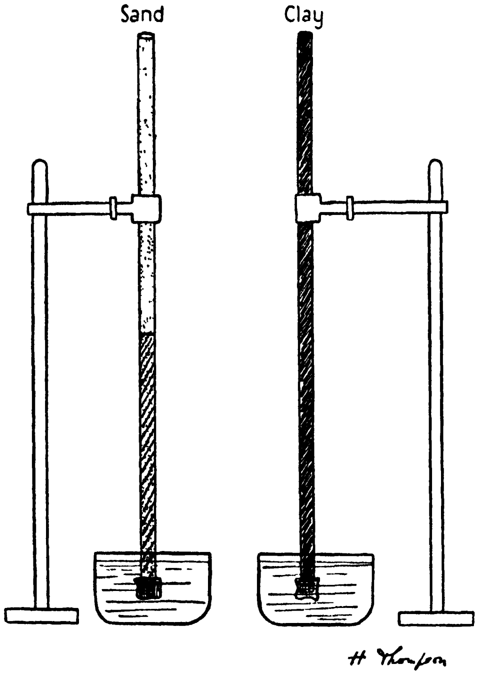



FIG. 25. Apparatus for comparing the rise of water in sand and clay.

being filled.) The tubes are held in clamp stands, and at the same time are lowered, so that the ends covered with muslin are in water in basins (see Fig. 25). The levels to which the water rises in the clay and in the sand are noted at intervals. The results on page 52 were recorded in one experiment. (Water passes slowly into completely dry soils.)

In all the experiments that have been made the water has risen more quickly at first in the sand than in the clay, but after a time the level in the clay is higher and the water continues to rise after the level in the sand is stationary.

For demonstration purposes, in addition to the experiments made by every pair of girls, two pieces of combustion tubing,

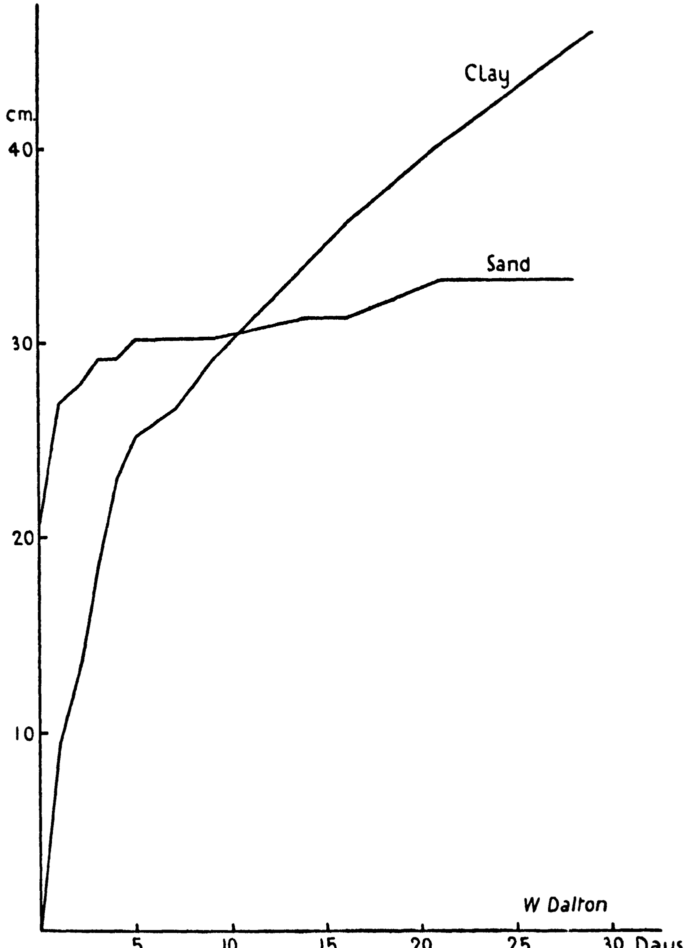



FIG. 26. Graph representing rise of water in sand and clay.

several feet long, one filled with oven-dried powdered clay and the other with oven-dried sand, as in the above experiment, are kept in the laboratory.

A graph showing the rise of water in sand and clay is seen in Fig. 26.

READINGS

| Date | Height of water in cm. in sand | Height of water in cm. in clay |
|---|---|---|
| Oct. 30 | 21·0 | 0 |
| ,, 31 | 27·0 | 9·5 |
| Nov. 1 | 28·0 | 13·5 |
| ,, 2 | 29·2 | 18·5 |
| ,, 3 | 29·2 | 23·2 |
| ,, 4 | 30·2 | 25·2 |
| ,, 6 | 30·2 | 26·7 |
| ,, 8 | 30·2 | 29·2 |
| ,, 13 | 31·4 | 34·2 |
| ,, 15 | 31·4 | 36·2 |
| ,, 20 | 33·4 | 40·2 |
| ,, 22 | 33·4 | 41·7 |
| ,, 27 | 33·4 | 44·7 |
| Finally | 35·6 stationary | 47·0 at top |

**To compare the permeability to air of sand and clay.** Two aspirators are filled with water, and each is fitted with an india-rubber cork with one hole. Through the hole is put the stem of a funnel which has been loosely plugged with a little cotton-wool. Equal weights of oven-dried sand and clay are mixed with equal quantities of water; some of the wet clay is put into one of the funnels and the same amount of wet sand into the other. The taps of the aspirators are turned; water runs out of the aspirator with sand in the funnel, but little or none out of the aspirator with clay in the funnel.

Sand is more permeable to air than clay.

**To determine the water capacity of soil.** A measured quantity of water is put into a tin, and the level marked inside the tin. The water is emptied out, and holes are knocked in the bottom of the tin. Soil is put in the tin and shaken down until it is at the same level as the water had been. The tin and soil are then stood in a shallow dish of water until the soil is saturated. Then the tin is taken out, and after the surplus water has been allowed to drain away, the tin and soil are weighed. The soil in the tin is then oven-dried until the weight is constant.[1]

The difference in the weights of the tin and soil, when saturated and when oven-dried, gives the weight of the water that

[1] See Fritch and Salisbury, *The Study of Plants*. Bell & Sons.

can be held by the measured volume of the given soil. The water capacity can then be determined in terms of the volume of the saturated soil since 1 c.c. of water weighs 1 gm.

In an experiment with peat from the bog in the J.A.G.S. heath it was found that it absorbed 72·5 per cent. of the volume of the saturated peat.

**To determine the percentage of humus in soil.** Soil is taken from some part of the botany gardens and oven-dried. A crucible is weighed, filled with the soil, and weighed again. It is then heated over a Bunsen burner, or better still, in a muffle furnace. The crucible is weighed at intervals and re-heated until the weight is constant. It now contains a red substance unlike the original soil. The percentage loss in weight is found and it is assumed that the loss in weight is caused by the disappearance of the decaying organic matter, the humus, but it includes also any water that was previously in chemical combination in the soil, and there may be slight loss of weight of the ash constituents.

PERCENTAGE OF HUMUS IN VARIOUS SOILS
SUMMARY OF EXPERIMENTS MADE AT J.A.G.S. IN THIRTEEN YEARS

| *Soil* | *No. of experiments* | *Percentage (average)* |
|---|---|---|
| *Garden Soil* | | |
| J.A.G.S. (Order Bed) | 40 | 13·33 |
| *Heath Soil* | | |
| J.A.G.S. | 56 | 18·61 |
| Keston | 4 | 24·91 |
| *Bog Soil* | | |
| J.A.G.S. | 55 | 68·79 |
| Keston | 20 | 65·39 |
| *Wood Soil* | | |
| Wood near Canterbury | 10 | 24·32 |
| New Wood, J.A.G.S. Dell | 18 | 24·81 |
| New Wood, J.A.G.S. Not Dell | 27 | 12·74 |

**Influence of colour on temperature of soil.** Two adjacent similar plots of ground were hoed; one had a light dressing of

soot until the surface was black, and the other a dressing of lime. A soil thermometer was put in each of the plots, the bulb at a depth of 6 inches.

READINGS OF THERMOMETERS TAKEN DURING FOUR YEARS

| *No. of days on which observations taken* | *No. of days on which temperature of dark soil higher* | *Percentage* | *No. of days on which temperature of dark soil the same* |
|---|---|---|---|
| 67 | 47 | 70·1 | 14 |

It was seen in the above experiments that on many days the 'black' soil absorbed more heat than the 'white'. The difference was greatest on hot sunny days.

The temperatures of the light and dark soils on successive school-days one June are shown below.

| *Date* | *Temperature of light-coloured soil* | *Temperature of dark-coloured soil* |
|---|---|---|
| | ° C. | ° C. |
| June 11 | 15·9 | 16·1 |
| ,, 12 | 16·0 | 16·2 |
| ,, 15 | 16·9 | 18·2 |
| ,, 16 | 17·6 | 18·0 |
| ,, 17 | 16·8 | 17·1 |
| ,, 18 | 18·0 | 18·5 |
| ,, 19 | 17·0 | 17·3 |

Experiments showing the influence of aspect on the temperature of soils are described in Chapter IX. Other soil experiments are omitted for want of space.

# THE BOTANY GARDENS

## VII

## HISTORY AND ORGANIZATION

'God Almighty first planted a garden. And indeed it is the purest of human pleasures. It is the greatest refreshment to the spirits of man, without which buildings and palaces are but gross handiworks.' BACON.

THE Botany Gardens of the James Allen's Girls' School, Dulwich, were begun in 1896 and, as far as is known, were the first gardens in a secondary school in England to be placed in charge of the pupils and used for the purpose of teaching botany. At that time many natural orders (now usually called families) were included in the botany syllabus of some examinations corresponding to the School Certificate Examinations of the present day. In order that there should be a first-hand knowledge of the plants belonging to these 'orders' between twenty and thirty 'order' beds were made. The 'order' beds soon formed only a part of the botany gardens. Plots for soil experiments (development of root tubercles in leguminous plants), plots for experimental work in carbon assimilation (as photosynthesis was then called), and plots for pollination experiments were added, also arrangements for climbing plants. A small cornfield was made, a small sand dune, a salt marsh, a chalk bed, a wood, and a bed for alpine plants, some addition being made in most years.

For fifteen years there was no grant of money for the botany gardens and the mistress and girls obtained some of the commoner plants. For some time there had been a great desire to have a lane in the school grounds, and in 1909 the Governors granted £10 for this purpose. The lane was made, and has been of great service as well as a great pleasure. (See Chap. IX.)

Other developments were needed, the cost of which could not be met by the girls, and application was made to the Board of Education for a yearly grant. In 1912 the Board arranged to make a yearly grant for at least three years. At the end of three years it was renewed, and has been given every year since, thus making it possible to have still further developments. These

developments have included a large pond, a smaller pond, freshwater marshes, salt marshes, more pollination beds, a larger heath containing a peat bog, a larger wood, a larger sand dune and pebble beach, a plot representing a meadow, a cornfield, plots for Mendelian experiments and manurial experiments, all added by degrees.

In 1926, the first year a census was taken, there were 591 species present in the botany gardens.

As already stated the work in the gardens is, and always has been, voluntary. It is done in out-of-school hours. The school is a day-school, and the chief time during which girls work in their gardens is the dinner-hour recess. For the last twenty years the average yearly number of girls in charge of botany gardens has been nearly 300. In many years every girl learning botany has had charge of a garden.

In the early days teacher and girls sometimes came in the holidays to help make new gardens. If it had not been for the enthusiasm shown by the girls, and the voluntary work done by them, the botany gardens could not have been made. At the present time girls, if they wish to work in the holidays, are allowed to do so at stated times, and many do come.

In term time the girls work in pairs and choose their partners from the same class. They have charge of a garden for a year, and are entirely responsible for it. Having put their hands to the plough they must not look back. Within certain limits the girls choose which gardens they will have, but the girls of the class, for example, studying water plants, must have charge of the ponds and marshes, but they settle among themselves how the parts shall be allotted.

The work is so arranged that a girl in the School Certificate form, who has moved up steadily through the school from the time she was about eleven, has had charge of parts of the lane, wood, pond or marshes, heath and bog, and also a pollination plot and an 'order' bed, in various years.

The botany gardens, in addition to being of immense help in botanical and zoological work, are a great source of pleasure in themselves to teachers and pupils.

The *aesthetic aspect* of the gardens has always been studied, not only for the sake of the girls in charge of the various parts, but for the sake of the school as a whole. In spring the lane

and wood with leaves of shrubs and trees unfolding, and primroses, bluebells, campions, and violets in flower; in summer the pollination beds and 'order' beds often masses of colour, the ponds and marshes with water-lilies, purple loose-strife, and meadow-sweet; in autumn the heath with heather and heath in flower, all help to make the gardens beautiful. If some plants belonging to a family are particularly beautiful, the girls in charge can grow as many specimens as space and the claims of other plants permit.

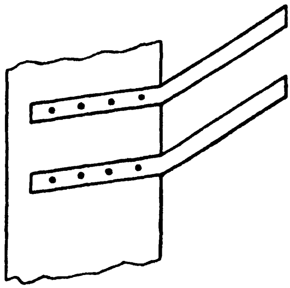


FIG. 27.

**Tools and tool sheds.** Before 1912 the tools were generally supplied by individuals, but one of the conditions of the Board of Education grant was that the girls were not to bear any part of the expense of the botany gardens.

As regards use and care of tools, the most satisfactory arrangement is for each girl, or pair of girls, to use during the year the same tools, and be responsible for them. For a long time there were not sufficient tools to make this possible, but gradually as, year by year, more were bought, they were numbered, and in some forms each pair of girls had the sole use of a tool, and was made responsible for its being in the right place in the tool shed. Some wire hooks, suitable for holding small tools, such as hand-forks and trowels, were found, price two shillings a dozen. These hooks were screwed on the walls of the tool shed and numbered, so that each small tool had its place. Also simple brackets made of two pieces of iron, three-quarters of an inch broad, bent at an angle, were fixed on shelves or other projections in the walls of the tool sheds, each to support a row of larger tools, such as spades and forks (Fig. 27). A long bar was also put down the middle of the sheds on which big spades and forks could be hung.

It is important when there is not much time for gardening that the workers should be able to find their tools easily, and put them away tidily, especially if there are many working at the same time. In the wood there are often sixty young girls at work.

For many years there was no tool shed, and then for some years only one small one, and no classification of tools was possible, but after a time three tool sheds were put in different parts of the garden. Rambler roses and other climbers were trained over the sheds to make them harmonize with their surroundings.

**Labels.** For sixteen years the girls paid for most of the labels, each girl contributing two pence every year. Each plant, or group of plants, had a small label with the English name on it. Also excellent large oblong labels were made of tin, sometimes 8 inches long, nailed on wooden supports with a pointed end to go into the ground. The wooden part was painted black, and the tin part enamelled black, and the owners of gardens painted names such as SALT MARSH in large white letters on the tin. It is easy each year to re-enamel the labels, and repaint the names if they have become indistinct.

**Reports.** At first only yearly reports were made of the gardens, or parts of gardens, but for more than thirty years monthly reports have been made on the work of the girls of each class, and good individual work has been singled out for commendation. There is also a report on the work of the year. All the reports are usually read out in the Hall by the Head Mistress.

**Animal life.** Although the object of this book is to give an account of experiments on plants, passing references will be made to the facilities the various gardens offer for the study of animals. The gardens at J.A.G.S. may well be called biology gardens.

**Visitors.** A great feature of the gardens has been the interest they have aroused in people not connected with the school. Teachers, and others interested in education, from Russia, France, Germany, Spain, Portugal, Sweden, India, Ceylon, South Africa, Australia, New Zealand, Japan, and the United States, have visited them, and in France, Sweden, and Spain, the J.A.G.S. botany gardens have been made the subject of theses, when teachers and people in administrative posts have

returned home. Many teachers in our own country also have visited the J.A.G.S. gardens. In the decade 1921–31 there are on record the visits of nearly 800 people.

**Formation of botany gardens elsewhere.** There have been numerous applications for information and guidance from those wishing to make botany gardens, and it is in the hope that others may benefit from the experience gained at Dulwich that practical details of the various gardens are given in the following chapters. The formation of botany gardens in schools in other parts of the country by some who have been educated at J.A.G.S., and by others who have visited the gardens, has been a source of great interest.

To any one who wishes to have botany gardens we would say that the great thing is to make a start, and not wait for perfect conditions.

'To watch the corn grow, or the blossoms set; to draw hard breath over plough-share or spade; to read, to think, to love, to pray—these are the things that make men happy.' RUSKIN.

## VIII

## POLLINATION EXPERIMENTS. CLIMBING PLANTS

VERY early in the history of the botany gardens plots for pollination experiments were dug. In 1900 experiments were made on garden pansies. After all the flowers had been removed, one bed of pansies was covered with coarse muslin on a frame, and close to it another bed was left uncovered. Many fruits were formed on the uncovered plants, none on the covered. Garden pansies do not form fruit when insects are excluded. (Beds containing wild pansy plants were covered with a muslin frame, and many fruits were formed.)

Experiments also were made to see if pollen is necessary for the formation of fruit in various plants. Stamens, while still in an unripe condition, were cut out of buds, and each bud was enclosed in a fine muslin bag. Other experiments were made to see if the shock of cutting out the stamens prevented the formation of fruit. Unripe stamens were cut out of buds as before, and then pollen from other flowers of the same species was applied to the stigmas, and the flowers were marked by tying cotton round the stalks. Very often the girls themselves suggested that this control experiment ought to be made.

After a time a modification was made. The control experiments were also tied in bags in order to make the two sets of experiments alike in all points except for the application of pollen. As the stigmas were often not ripe when the stamens were cut out, later the bags round the control experiments were untied, the stigmas were repollinated, and the bags retied.

Experiments also were made on a great number of plants to see if self-pollination can take place if insects are excluded. Flower buds of many plants were enclosed separately in muslin bags.

Many of these experiments have been original investigations, as sometimes neither teacher nor pupils knew what the results would be and records of the pollination of the particular plants chosen are not always to be found in books.

The pollination experiments that have been made every year for more than thirty years thus fall into two classes:

1. Experiments to see if pollen is necessary for the formation of fruit in various plants.
2. Experiments to see if self-pollination can take place in various plants in the absence of insects.

The following tables record the results of the pollination experiments of twenty-one years:

JAMES ALLEN'S GIRLS' SCHOOL
SUMMARY OF POLLINATION EXPERIMENTS OF 21 YEARS

*To see if pollen is necessary for the formation of fruit*

*Part I.* CUTTING OUT THE STAMENS AND TYING THE BUDS IN BAGS

| *Plant* | *No. of expts.* | *No. of fruits* | *Percentage of fruits* |
|---|---|---|---|
| 1. Bluebell | 85 | 0 | 0 |
| 2. Buttercup | 40 | 0 | 0 |
| 3. Eschscholtzia | 11 | 0 | 0 |
| 4. Honesty | 14 | 0 | 0 |
| 5. Stock | 16 | 0 | 0 |
| 6. Toadflax | 16 | 0 | 0 |
| 7. Snapdragon | 145 | 1 | 0·68 |
| 8. Sea Campion | 76 | 1 | 1·3 |
| 9. Canterbury Bell | 298 | 6 | 2·0 |
| 10. Foxglove | 472 | 10 | 2·1 |
| 11. Red Campion | 55 | 2 | 3·6 |
| 12. Wallflower | 701 | 29 | 4·1 |
| 13. Columbine | 280 | 18 | 6·4 |
| | 2,209 | | |

*Part II.* CUTTING OUT THE STAMENS, APPLYING POLLEN FROM OTHER FLOWERS TO THE STIGMAS, AND TYING THE BUDS IN BAGS[1]

| *Plant* | *No. of expts.* | *No. of fruits* | *Percentage of fruits* |
|---|---|---|---|
| 1. Bluebell | 26 | 26 | 100 |
| 2. Buttercup | 69 | 69 | 100 |
| 3. Eschscholtzia | 10 | 7 | 70 |
| 4. Honesty | 17 | 17 | 100 |
| 5. Stock | 27 | 27 | 100 |
| 6. Toadflax | 14 | 13 | 92·8 |
| 7. Snapdragon | 81 | 70 | 86·4 |
| 8. Sea Campion | 78 | 57 | 73·0 |
| 9. Canterbury Bell | 381 | 362 | 95·0 |
| 10. Foxglove | 285 | 241 | 84·5 |
| 11. .. | .. | .. | .. |
| 12. Wallflower | 540 | 517 | 95·7 |
| 13. Columbine | 264 | 251 | 95·0 |
| | 1,792 | | |

[1] Buds tied in bags only in later years.

*To see if self-pollination can take place in various flowers in the absence of insects*

| *Plant* | *No. of expts.* | *No. of fruits* | *Percentage of fruits* |
|---|---|---|---|
| 1. Broom | 64 | 0 | 0 |
| 2. Foxglove | 66 | 0 | 0 |
| 3. Yellow Iris | 82 | 0 | 0 |
| 4. Tree Lupin | 24 | 0 | 0 |
| 5. Monkshood | 61 | 0 | 0 |
| 6. Pansy | 69 | 0 | 0 |
| 7. Raspberry | 25 | 0 | 0 |
| 8. Everlasting Pea | 416 | 4 | 0·9 |
| 9. Scarlet Runner Bean | 57 | 1 | 1·75 |
| 10. Yellow Toadflax | 46 | 1 | 2·1 |
| 11. Gorse | 48 | 1 | 2·0 |
| 12. Anchusa | 40 | 1 | 2·5 |
| 13. Adonis | 8 | 8 | 100 |
| 14. French Bean | 19 | 19 | 100 |
| 15. Eating Pea | 112 | 112 | 100 |
| 16. Loganberry | 109 | 107 | 98·1 |
| 17. Corncockle | 40 | 39 | 97·5 |
| 18. Sweet Pea | 51 | 49 | 96 |
| 19. *Lychnis coronaria* | 97 | 93 | 95·8 |
| 20. Columbine | 360 | 333 | 92·5 |
| 21. Poppy | 85 | 77 | 90·5 |
| 22. Wallflower | 126 | 113 | 89·6 |
| 23. *Cheiranthus Allionii* | 100 | 62 | 62 |
| 24. Hollyhock | 84 | 51 | 60·7 |
| 25. Marsh Marigold | 168 | 100+2 small | 60·7 |
| 26. Soapwort | 43 | 17 | 39·5 |
| 27. Eschscholtzia | 72 | 26 | 36·1 |
| 28. Nigella | 317 | 115 good 28 poor | 36·2 8·8 |
| 29. American Pillar Rose | 49 | 11 | 22·4 |
| 30. Snapdragon | 1,288 | 259 | 20·1 |
| 31. Delphinium (perennial) | 847 | 169 | 19·9 |
| 32. *Delphinium consolida* | 229 | 42 | 18·3 |
| 33. Strawberry | 672 | 121 | 18 |
| 34. Figwort | 74 | 10 | 13·5 |
| 35. Canterbury Bell | 98 | 5 | 5·1 |
| 36. Lupin | 65 | 3 | 4·6 |
| | 6,111 | | |

At first no exact record of all the experiments made each year was kept. Each girl described in her own book the experiments she herself had made, and recorded her own results.

Later, the results of the experiments made by all the members of the class that year were recorded by each girl, and, later still, the summary of all the experiments of former years was given



(*Photo Elliott & Fry*)

Fig. 28. Pollination Experiments in the Botany Gardens, 1915

to the class *after* the results of the year's experiments had been fully discussed and noted.

The girls are often eager to take muslin and make bags at home, so that more time can be spent in the lesson on actually making experiments. Sometimes pins have been used instead of cotton in making the bags and have been found satisfactory.

The pollination experiments, in particular, afford a training in manipulation, in recording observations, in comparing the results with those obtained by others, and in drawing conclusions from a great number of facts.

There is now available for reference the results of thousands of experiments in pollination made by the girls.

**Sources of error in pollination experiments.** The girls who make the pollination experiments are young and have had little experience in carrying out experiments. It is delicate work cutting out stamens from small buds while on the plants. They do the work unaided, though under supervision, but the time allotted does not permit of all the work being examined.

It is possible that occasionally buds at a too advanced stage have been taken. The most frequent source of error, however, is that the muslin bags are not tied sufficiently tightly round the buds. Experiments have been seen in which not only small but large insects could crawl inside the bags.

Another source of error is the inclusion of more than one bud in the bag. Even when apparently only one bud is enclosed, if the growing point of the stem is included, more buds may be formed after the original bud is enclosed.

When results are considered and compared in class reasons for discrepancies are often suggested by the girls.

As a rule the girls feel their responsibility in helping to build up records, and work well in the gardens.

**Pollination in annuals and perennials.** It has been noticed that in some closely allied species experiments show that self-pollination can take place in the annuals and not in the perennials. The advantage to an annual of being self-fertile is obvious.

Reference can be made to the experiments recorded on p. 62.

Sweet Pea. *Lathyrus odoratus.* Annual.
96 per cent. formed fruit when insects were excluded.
Everlasting Pea. *Lathyrus latifolius.* Perennial.
0·9 per cent. formed fruit when insects were excluded.

**Material for pollination experiments.** The plants on which pollination experiments are often made are grown in more than one part of the garden, so as to give opportunity for many girls at the same time to make experiments on the flowers. There are, generally, paths on three sides of the pollination plots, sometimes on four sides, and easy access to the plants is thus given. There may be fifty or more girls making pollination experiments at the same time in the garden.

### POLLINATION OF PRIMROSE

Primroses do not seem to have a great attraction for bees even when they are growing near a hive. The bee-flies (Bombylids), however, make many visits.

Darwin wrote several papers on the pollination of the primrose, cowslip, and oxlip in 1861. He suggested that night-flying moths pollinated the primrose. This theory has again been brought forward in recent years, but has met with opposition. As there have been such conflicting theories regarding the pollination of the primrose it was decided in 1924 that experiments should be made in the J.A.G.S. gardens.

Three wooden frames were made and covered with coarse muslin. They were placed over clumps of primrose plants in the early part of the year. The frames were 4 ft. 7½ in. long, 3 ft. 3 in. wide, and 2 ft. high, and there seemed plenty of air inside them.

The muslin was not sufficiently near the plants to allow insects to insert their proboscides through it to the flowers, as had been seen in other experiments elsewhere.

One set of primrose plants was covered day and night, one by day only, and one by night only.

There were unexpected delays in carrying out the experiments. One difficulty was the time of placing the frame over the plants which were to be exposed only at night. The school is a day-school, and neither teachers nor pupils are at school when the sun rises in March and April. Finally, the grounds-

man arranged to cover the night-exposed plants at 6 a.m. and uncover the plants which were to be exposed in the day.

SUMMARY OF RESULTS OF EXPERIMENTS. 3 YEARS

| | *Treatment* | *Plants* | *No. of flowers examined* | *No. of fruits* | *Percentage* |
|---|---|---|---|---|---|
| A | Covered day and night | Thrum-eyed, Pin-eyed | 102 | 0 | 0 |
| B | Exposed by night only | Thrum-eyed | 140 | 2 | 2·72 |
| | | Pin-eyed | 117 | 5 | |
| C | Exposed by day only | Thrum-eyed | 241 | 214 | 91·05 |
| | | Pin-eyed | 262 | 244 | |

The above experiments seem to show:

1. The primroses were not self-pollinated.
2. Night-flying insects played little part in the pollination of these primroses.
3. Day-flying insects were the chief agents in pollination.

It is possible that, even in March and April, 6 a.m. is too late an hour at which to cover the plants meant to be exposed to night-flying insects only. In one of the years taken as an example, the times of the rising of the sun were as follows: April 4th 5.31, April 18th 4.59, April 30th 5.35 (summer time).

Experiments made in a fourth year were continued until a late date (June 5th). The sun rose on May 31st at 4.50 a.m. (summer time). The number of fruits on the plants exposed by night until 6 a.m. was much greater than in other years. The results of all the experiments including those of the fourth year were: percentage of fruits on plants covered by day and night, 0; on plants exposed by night until 6 a.m., 12·3; on plants exposed only by day, 90·6.

The experiments on the pollination of the primrose are still being carried on at J.A.G.S.

Mr. Marsden-Jones from direct and experimental evidence concluded that day-flying insects do pollinate primroses effectively, and that nocturnal insects (Lepidoptera) play no part whatever in the pollination of the primrose.[1]

**Observation of visits of insects to flowers.** Visits of insects to flowers are a great source of interest. From very early days

[1] *Journal of the Linnean Society*, Botany, December 1926.

classes went into the garden to watch insects visiting flowers. The girls noted the kind of insect visiting the flower, the part of the flower on which the insect alighted, the part of the insect dusted with pollen, the number of flowers of the same species visited by the same insect in one minute, and any other interesting facts connected with pollination.

It was soon realized that the position of the nectary, when present, had an important bearing on the pollination of the flower: whether the nectar was easily accessible, whether the insect in obtaining nectar received pollen, and if so, whether the insect was likely to leave pollen on the stigma of the same flower, or of the next flower of the same species visited. The time of ripening of the stamens was often another important observation.

The classes in some years were large, containing more than forty girls, and the time in the gardens was only half an hour. Such classes were divided into small bands, each with a leader.

Most records of early observations were not kept, but some are available. The following were made in 1905–6 by 76 girls working in divisions in the garden for one period of 30 minutes.

1. Visits of bees to 40 species:

Borage
*Bramble
Canterbury Bell
Clover
*Comfrey
Dead-nettle, Purple
*Dead-nettle, White
Figwort
Foxglove
Funkia
Geranium (Pelargonium)
Geranium, Wild (sp.)
Goat's Rue
Hogweed
Hollyhock
*Larkspur
Lobelia
Lupin
Mallow
Marigold
Meadow Rue
Mint
*Monkshood
Mullein
'Nasturtium'
Pansy
*Pentstemon
Poppy
Radish
Runner Bean
Rose, Dog
Salvia
Sea Holly
†Snapdragon
Speedwell
Sunflower
Thistle
Vetch
*Virginia Stock
Yellow Horned Poppy

* Flowers seen visited by humble-bees, in some cases in addition to hive bees.
† Only seen visited by humble-bees.

2. Visits of wasps to 20 species. Figwort was by far the most attractive of these plants to wasps.
3. Visits of flies to 7 species.
4. Visit of moth to 1 species. Evening primrose (the girls leave school in the afternoon).

The total number of species seen visited by insects in one lesson of 30 minutes by 76 girls was 55. Individual girls often described the visits of insects to 8, 9, or 10 plants of different species.

Thirty-two girls watched bees visiting salvias in different parts of the garden, 30 watched bees on hollyhocks, 20 watched bees on poppies, 20 on 'nasturtiums', and 21 girls saw wasps visiting figwort.

**Flowers of same species visited by bees.** Bees usually visit the flowers of the same species as long as they can. Darwin pointed this out in 1876 and stated that Aristotle had observed the fact more than 2,000 years earlier. This habit enables the bee to work more quickly. The advantage to the plant is evident.

**Number of flowers visited in one minute.** Bees are great workers, in fact they overwork. The life of a working bee is a short one. Also they fly quickly. Darwin found that humble-bees sometimes fly at the rate of ten miles an hour.

In the record quoted on pp. 66–7 of insects seen visiting flowers at J.A.G.S., the number of flowers visited in one minute was noted in each case. The following are some of the numbers:

| *Insect* | *Plant* | *No. of flowers visited in 1 minute* |
|---|---|---|
| Bee | Bramble | 20 |
| ,, | Dead-nettle (white) | 19 |
| ,, | Foxglove | 12 |
| ,, | Hollyhock | 12 |
| ,, | Larkspur | 24 |
| ,, | Marigold (heads) | 30 |
| ,, | 'Nasturtium' | 12 |
| ,, | Pansy | 15 |
| ,, | Salvia | 16 |
| ,, | Virginia Stock | 13 |
| Wasp | Figwort | 22 |

. **Species of insects visiting flowers.** It is evident that a greater number and greater variety of insects will visit 'open' flowers with exposed nectar than irregular flowers with deeply concealed nectar. More than sixty species of insects have been noted visiting buttercup flowers. Müller has shown that even with apparently comparable 'flowers' (inflorescences) as those of the Compositae and Umbelliferae the species of insects visiting the flowers are different, the nectar being completely exposed in the Umbelliferae, and slightly concealed in the corolla tube of the florets in the Compositae.

| *Plant* | *No. of species visiting flowers* | *Butterflies and moths* | *Bees* | *Flies* | *Other insects* |
|---|---|---|---|---|---|
| Hogweed | 118 | 0 | 13 | 49 | 56 |
| (Cow Parsnip) | Percentage | 0 | 11 | 41·5 | 47·5 |
| Dandelion | 93 | 7 | 58 | 21 | 7 |
| | Percentage | 7·5 | 62·4 | 22·6 | 7·5 |

**Provision of plants for insect visitors.** It is well to have in the garden the following plants if only to observe the visits of insects to them: buttercup, broom, borage, dead-nettle, foxglove, figwort, larkspur, gorse, monkshood, sweet pea, pinks, snapdragon, salvia. They can be grown in the 'order' beds, and in other parts used for pollination experiments. It is a great advantage to have clumps of them in different places, so that many girls can be watching the visits of insects at the same time.

The most exciting plant to watch is salvia. When the bee pushes its proboscis down the corolla to the nectar, and hits the lower ends of the two anthers, the quick way in which the upper ends swing roung and hit it on the back, leaving a patch of pollen, is a constant joy to see.

The 'explosions' of pollen in broom and gorse are also popular, and great interest is shown in the disappearance of the bee into the snapdragon flower and its reappearance, with pollen on its back, as it pushes opens the corolla and walks out backwards. Borage and anchusa are also good 'bee plants'.

**Provision of insect visitors for plants.** At one time there was a beehive in the garden, and girls had lessons in bee-keeping after school, but the main reason for having the hive was that there should be many bees visiting flowers.

## FURTHER RECORDS OF INSECTS SEEN VISITING FLOWERS (1927–30)

Number of Flowers at J.A.G.S. seen visited by

| | | | |
|---|---|---|---|
| Bees | 122 | Wasps | 14 |
| Butterflies | 34 | Moths | 5 |
| Flies | 24 | Beetles | 1 |

Number of Flowers at J.A.G.S. seen visited by

| | |
|---|---|
| 1. Bees only | 87 |
| 2. Bees and butterflies | 10 |
| 3. Bees, butterflies, and flies | 5 |
| 4. Bees, butterflies, and wasps | 4 |
| 5. Bees and flies | 4 |
| 6. Bees, flies, and wasps | 1 |
| 7. Bees and wasps | 7 |
| 8. Bees and moths | 3 |
| 9. Bees and beetles | 1 |
| 10. Butterflies only | 11 |
| 11. Butterflies and flies | 3 |
| 12. Butterflies and moths | 1 |
| 13. Flies only | 11 |
| 14. Wasps only | 2 |
| 15. Moths only | 1 |
| Total | 151 |

## RECORDS OF VISITS TO PLANTS OF TWO FAMILIES CHOSEN FROM RECORDS OF VISITS TO PLANTS OF THIRTY-FIVE FAMILIES

### LEGUMINOSAE

| | *J.A.G.S. Record* | | **Knuth Record* | |
|---|---|---|---|---|
| 1. *Bees.* | | | | |
| Broad Bean | | Humble | | Humble |
| Bird's-foot Trefoil | Hive | | Hive | Humble |
| Broom | Hive | | Hive | Humble |
| Clover—red | | Humble | Hive | Humble |
| Clover—white | Hive | Humble | Hive | Humble |
| Everlasting Pea | | Humble | | Humble |
| Gorse | Hive | Humble | Hive | Humble |
| Lupin | Hive | Humble | Hive | Humble |
| Tree Lupin | | Humble | | Humble |
| Melilot | Hive | | Hive | |
| Runner Bean | | Humble | | Humble |
| Sainfoin | Hive | | Hive | Humble |
| Sweet Pea | Hive | | | 'Bee' |
| Vetch | | Humble | Hive | Humble |
| Yellow Vetchling | Hive | Humble | | |

* Knuth incorporated Müller's records.

| | *J.A.G.S. Record* | | *Knuth Record* | |
|---|---|---|---|---|
| 2. *Butterflies.* | | | | |
| Broad Bean | Cabbage | | | |
| Lupin | 'Butterfly' | | | |
| 3. *Wasps.* | | | | |
| Lupin | 'Wasp' | | | |
| 4. *Flies.* | | | | |
| Broom | Hover | | Flies | |

COMPOSITAE

| | *J.A.G.S. Record* | | *Knuth Record* | |
|---|---|---|---|---|
| 1. *Bees.* | | | | |
| Aster | | Humble | Hive | Humble |
| Chicory | Hive | | Hive | |
| Coltsfoot | Hive | | Hive | Humble |
| Cornflower | Hive | Humble | Hive | Humble |
| Perennial Cornflower | Hive | Humble | | |
| Daisy | Hive | | Hive | Humble |
| Dahlia | | Humble | | Humble |
| Dandelion | | 'Bee' | | Humble |
| Helenium | Hive | | Hive | |
| Knapweed | | Humble | Hive | Humble |
| Marigold | Hive | | Hive | Humble |
| Ox-eye Daisy | | Humble | | Humble |
| Sunflower | | Humble | Hive | Humble |
| 2. *Butterflies.* | | | | |
| Autumnal Hawkbit | Fritillary<br>Meadow Brown | | Fritillary<br>Meadow Brown, &c. | |
| Cornflower | Cabbage | | Blue sp. | |
| Crepis | Large White<br>Blue | | Small White<br>Blue, &c. | |
| Dahlia | Small White | | | |
| Knapweed | Large Heath<br>Tortoise-shell | | Heath sp.<br>Tortoise-shell, &c. | |
| Marigold | Large White | | | |
| 3. *Wasps.* | | | | |
| Cornflower | 'Wasp' | | | |
| White Daisy | 'Wasp' | | | |
| 4. *Flies.* | | | | |
| Aster | Hover | | Hover | |
| Golden Rod | 'Fly' | | Flies | |
| Ox-eye Daisy | 'Fly' | | Flies | |
| Marigold | 'Fly' | | Flies | |
| Wormwood | 'Fly' | | Flies | |
| 5. *Moths.* | | | | |
| Carline Thistle | Burnet | | 2 Lepidoptera | |

### CLIMBING PLANTS

The next addition to the botany gardens was a number of climbing plants. In 1901 two screens, 6 ft. high, 11 ft. 6 in. long, were made just outside the laboratory, one of trellis work, and the other of wire-netting attached at intervals to wooden uprights. Climbing plants were put on each side. It was found better to have the plants near screens than near a wall, as girls can stand each side of a screen, and make experiments or draw the various climbing organs. The following were planted: *Clematis vitalba* (traveller's joy), *Clematis flammula*, *Clematis montana*, field bindweed, honeysuckle, hop (two plants), 'nasturtium', *Akebia*, *Bignonia*, Dutchman's pipe, passion flower, scarlet runner bean, and vine.

The plants were chosen so that different methods of climbing could be studied; namely, by stems twining clockwise, by stems twining anti-clockwise, by tendrils formed from stems and from various parts of the leaf, and by hooks.

In 1915 another arrangement for climbing plants was made elsewhere in the garden. The framework was constructed of vertical and horizontal larch poles, to which other poles of different diameters, driven into the ground at various angles from the vertical, were nailed.

### I. PLANTS CLIMBING BY TWINING STEMS

**1. Rate of revolution.**

| *Plant* | *Direction of twining* | *Locality* | *No. of expts.* | *Av. time of 1 revolution* | *Darwin's results* |
|---|---|---|---|---|---|
| | | | | hrs. min. | hrs. min. |
| Field Bindweed or Convolvulus | Anti-clockwise | Garden | 18 | 2 8 | |
| Hop | Clockwise | ” | 73 | 2 35 | 2 8*<br>2 31 |
| Scarlet Runner | Anti-clockwise | Class-room | 67 | 2 17 | 1 57 in green-house |
| Scarlet Runner | ” | Garden | 38 | 2 37 | |

* THE HOP. From seven observations on the hop plant made in April and August, Darwin found that 'the average rate during hot weather and during the day is 2 hrs. 8 min. for each revolution'.

From observations on an internode of a hop plant in a pot kept day and night in

**Scarlet runner bean.** The observations made at J.A.G.S. were on plants growing in the garden and also on plants in pots indoors. The length of the longest lesson in which observations were made was 1 hour 30 minutes, and in most years the lessons were shorter than this. Continuous observation while the stem of any of the above plants made a complete revolution was impossible, and girls had to finish their observations in their free time.

If they allowed some time to elapse between successive observations there was a danger that the stem might have made one or more complete revolutions in addition to a fraction of one. To try to overcome this difficulty in the case of runner beans, plants in pots with their stems supported by thin stakes were put in the *class-room*, one plant for every pair of girls. It was easier for girls in any free minutes between classes, or before school, to note the position of the tip of the stem of a plant in their room, than to go into the garden.

A piece of cotton, with a small weight at the end, held near the tip of each stem, acted as a plumb-line. The pots were placed on white paper, and, with the help of the plumb-line, marks were made on the paper vertically below the stem tip. The position of the tip was marked, at intervals, and the time also was recorded.

**2. Thickness of support.** Pieces of cotton and string were tied in a vertical position near convolvulus, Dutchman's pipe, and hop, and the stems of these plants twined round them.

Ash poles of various diameters (2¾, 3, 3½, 4, 4½ in.) were driven into the ground near the hop plants on the original screens. The hop stems twined round all the poles. It was not easy to obtain ash, or other poles, of greater diameter than 4 in., and of practically the same diameter throughout the length, so wooden cylinders were made 5 and 5½ in. in diameter and 30 ins. high. Hop stems were tied once against the bottom of the cylinders. They just, and only just, climbed round the

Darwin's room when he was ill, Darwin found that 'the regular revolutions from ninth to thirty-sixth inclusive were effected at the average rate of 2 hrs. 31 mins.'. The movement was retarded on cold nights.

Speaking generally of plants climbing by twining stems Darwin stated that 'a decrease in temperature always caused a considerable retardation in the rate of revolution'.

cylinder the diameter of which was 5½ in., and this was the maximum thickness of the supports round which the hop stems twined.

3. **Angle of inclination of support.** Before the new arrangement for climbing plants was made, poles and sticks were put in the ground near the original screens, at various angles from the vertical, 30°, 45°, 60°, 90°.

*Akebia*, hop, and convolvulus twined round poles and sticks at 45° from the vertical, but of the many climbing plants watched only convolvulus and *Akebia* stems twined round horizontal supports. 45° seems a critical angle in many cases.

4. **Smoothness of support.** Long glass rods were placed in a vertical position near hop, *Akebia*, Dutchman's pipe, and convolvulus plants. The stems of all the plants twined round the rods. The glass rods were then coated with paraffin wax, and smooth brass vertical rods were placed near the plants. The stems twined round all the vertical supports. As far as has been tried the smoothness of the supports used has been no obstacle to the twining of the stems.

5. **Twisting of stems.** The stems of twining plants become twisted as they revolve. A good way of seeing this is to paint a line along the convex side of the twining stem, and watch the position of the line as the stem makes a complete revolution.

6. **Effect of inversion of plants.** Many runner bean plants with their stems twining round wooden sticks have been inverted. The youngest part of the stem becomes unwound and the tip twines in the opposite direction.

7. **Effect of placing plants with twining stems on a clinostat.** The stems of plants attached horizontally and rotated slowly did not twine.

8. **Effect of absence of light.** The stems of runner beans and other twining plants do not twine in the absence of light.

It has been pointed out that the cause of the contradictory statements made by various experimenters has been the *total* absence of light not being a condition of all the experiments.[1]

[1] Priestley, *The New Phytologist*, 1925.

The stems of plants which are only very faintly illuminated may continue to climb.

At J.A.G.S. runner bean plants were put in the dark-room in the part farthest from the door, a case of brown paper was put over them, and the plants were never taken into the light during the progress of the experiment. When light was needed, a ruby lamp was used. The stems did not twine round the sticks.

### II. PLANTS CLIMBING BY TENDRILS

Many experiments have been made at J.A.G.S. to test the sensitiveness of tendrils of various plants on the screens, but after 1909 there were better opportunities of making these experiments in the lane. A record of some of the experiments will be given in Chapter IX.

# IX

## THE LANE

IN 1909 the Governors made a special grant of £10 for a lane. A ditch and a hedgerow were made on each side of a grass walk 8 ft. wide. The ditch was 2 ft. deep, 12 in. wide at the bottom and at first 18 in. wide at the top, but afterwards it was found necessary to make the sides more sloping. The soil for the hedgerow was dug 2 spits deep, and the soil from the ditch was added.

One hundred and twenty-five native shrubs, such as could be found in country lanes, were planted. The greater part of the hedgerow consisted of hawthorns, beech, hedge maple, hazel, holly, oak, with brambles, dog-roses, honeysuckle, traveller's joy, and white bryony at intervals. It was soon found necessary to put more soil in order to make a bank on which small plants could grow.

It was some time before the lane looked like a real country lane, but many girls took a great interest in it, and brought primroses, violets, Jack-by-the-hedge, dead-nettles, stitchwort, and other plants, and it has been for many years now an especially favourite part of the garden in spring.

The lane at first was about 100 ft. long. It was lengthened in 1910, and again in 1911, 1912, and 1914. The present length is 163 ft.

The transect represents a vertical section of the lane with typical plants growing in it (Fig. 29).

The youngest girls who learn botany usually have charge of the lane. They prefer to work in pairs and have their own special parts for which they are responsible. In lesson time the same plants in spring, summer, autumn, and winter can be studied, and when possible the whole plant is taken. In this way a knowledge is gained of roots, underground stems, above-ground stems, foliage leaves, flowers, fruits, seeds, and seedlings. The lane is used by older girls also who carry out various experiments described later.

The lane proved so useful, not only in lesson time, but as a source of specimens, that it was decided in 1915 to make a

considerable extension, but there was only sufficient space available to make a hedgerow and ditch on one side in continuation of the hedgerow and ditch of the first part. The part of the lane added in 1915 was 150 ft. long. An additional 20 ft.

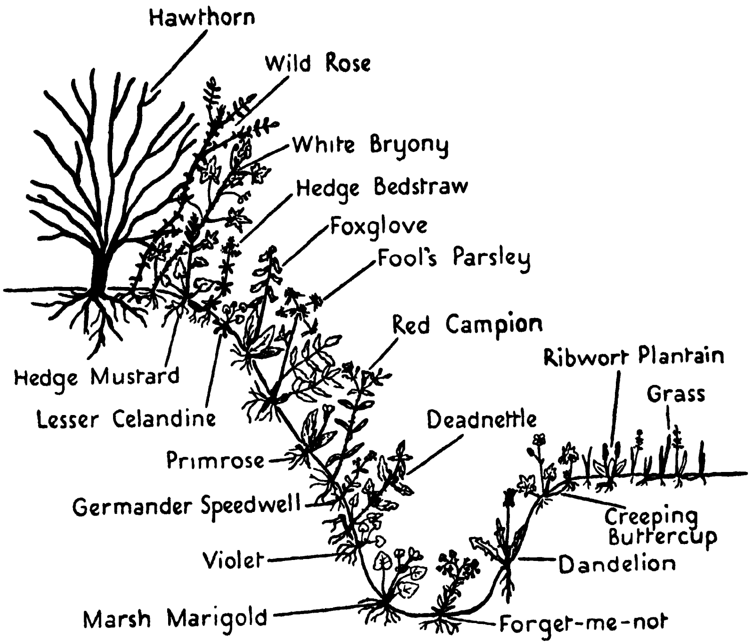



FIG. 29. Transect of Hedge. James Allen's Girls' School. (E. M. Delf).

has recently been made. Profiting by the experience gained when the first part was made, the ditch was made deeper, and wider at the top, and the sides were made to slope more than those in the original lane. The shrubs and small trees are the same species as those planted in 1909, with the addition of wayfaring tree, gean, bird cherry, white beam.

Forty climbing plants were added: bramble, black bryony, honeysuckle, traveller's joy, white bryony, wild rose.

Typical lane plants were put on the bank.

**Growth of plants.** After a time when the shrubs had grown they were cut back every autumn. In country lanes 'hedging

and ditching' are usually necessary. Some of the plants on the bank increased in number so much that many had to be uprooted. Coltsfoot, hogweed, and wild chervil, for example, tended to crowd out smaller, more delicate plants.

At first the spindle trees were disappointing. Six had been planted in the first part of the lane and three in the newer part, but no fruit was seen for many years. It was ten years before the beautiful fruits with their crimson walls and orange seed-coverings did appear, and now the spindle trees in fruit in the autumn are one of the features of the lane.

We heard from a horticultural firm that spindle trees do not usually fruit until 10 or 12 years old, so those who have planted them must not despair if the trees do not bear fruit at once.

### CLIMBING PLANTS IN THE LANE

**1. Twining plants.** There are in the lane black bryony and honeysuckle plants twining clockwise, woody nightshade twining indifferently, clockwise or anti-clockwise, and greater bindweed anti-clockwise.

Experiments on twining plants have been described in Chapter VIII.

**2. Scramblers.** These are represented by bramble, cleavers, and wild rose.

**3. Tendril climbers.** White bryony and traveller's joy have been put in several parts of the lane. Experiments are often made to test the sensitiveness of tendrils of various plants in the lane and of those growing on the screens. The girls bring watches and small clocks with seconds hands to the lesson.

1. The tendrils are rubbed and the time is noted before curvature takes place.

The following table gives some results obtained one day in the summer by a small class junior to the School Certificate class.

In these experiments the tendrils were just rubbed, the number of strokes up and down were not counted. In later experiments greater uniformity of treatment was introduced. Three strokes were made, and the time was recorded before the tendril changed from being straight | to curved Ր.

SENSITIVENESS OF TENDRILS

| *Plant* | *Locality* | *No. of expts.* | *Average time before coiling takes place* |
|---|---|---|---|
| | | | min. sec. |
| *Clematis vitalba* (Traveller's Joy) | On screen and in lane | 17 | 1 21 |
| *Clematis flammula* | On screen | 7 | 24·6 |
| *Clematis montana* | On screen | 19 | 1 13 |
| Everlasting Pea | Near screen | 17 | 1 2 |
| Passion Flower | On screen | 17 | 54 |
| White Bryony | In lane | 17 | 36 |

2. Very light objects, such as short pieces of cotton placed on young tendrils, have also been used to cause curvature, and the time has been noted before curvature took place. A long piece of cotton was weighed in a chemical balance and measured lengths were cut off and the weight was calculated. In one set of experiments each piece of cotton weighed 0·0057 gm., and the weight was sufficient to cause the tendrils of white bryony and *Clematis montana* to coil. In another set pieces of cotton weighing 0·113 gm. and 0·208 gm. were used.

The results of some experiments made in one lesson are given below:

RESPONSE TO WEIGHT OF PIECE OF COTTON

| *Plant* | *Locality* | *Weight of each piece of cotton* | *No. of expts.* | *Average time before coiling took place* |
|---|---|---|---|---|
| | | gm. | | sec. |
| White Bryony | Lane | 0·133 | 8 | 75 |
| | | 0·208 | 7 | 59 |
| Everlasting Pea | Near screen | 0·133 | 13 | 97 |
| | | 0·208 | 10 | 61 |

It is not claimed that the girls succeed in finding the exact time that elapses in various plants between the application of a stimulus and a curvature of a tendril, but it is an interesting piece of work and gives new ideas on the sensitiveness of tendrils.

**Influence of aspect on time of flowering of plants.** One side of the lane has a southerly aspect, the other a northerly one. Observations of the time of flowering of plants of the same

species are made. It is found there is generally a marked difference, in some cases nearly a month.

| Plant | *Earlier flowering in successive years of plants on side of lane with southerly aspect* | | | |
|---|---|---|---|---|
| | days | days | days | days |
| Bluebell | 18 | 8 | 4 | 9 |
| Wild Chervil | 16 | 2 | 7 | 9 |
| Lesser Celandine | 23 | 16 | 14 | 7 |
| Pink Campion | | 5 | 6 | 5 |
| Primrose | 18 | 25 | 12 | 7 |
| White Dead-nettle | | 9 | 30 | 30 |

**Influence of aspect on soil temperatures.** Two soil thermometers were put in the lanc, one (A) on the side with a southerly aspcct and one (B) on the side with a northerly aspect.

The following table gives a summary of readings taken during four years.

READINGS OF THERMOMETERS IN SOIL ON THE TWO SIDES

| *No. of days on which observations taken* | *Reading of A higher than of B* | *Reading of A the same as of B* | *Percentage* |
|---|---|---|---|
| 84 | 75 days | | 89·3 |
| | | 4 days | 4·76 |

## ANIMAL LIFE IN THE LANE

Lesson times are often spent out of doors studying various animals in the lane. The lane affords facilities for the study of the life-histories and habits of the common cross spider, ladybirds, caterpillars, snails, bees, wasps, flies, and earthworms. Birds have made their nests in the lane.

## PLANTS OF THE LANE

SHRUBS AND SMALL TREES:

| | |
|---|---|
| Beech | *Fagus sylvatica* |
| Bird Cherry | *Prunus Padus* |
| Blackthorn | *Prunus spinosa* |
| Crab Apple | *Pyrus Malus* |
| Dogwood | *Cornus sanguinea* |
| Gean | *Prunus avium* |
| Hawthorn | *Crataegus Oxyacantha* |
| Hazel | *Corylus Avellana* |

**Shrubs and Small Trees** (*continued*):

| | |
|---|---|
| Hedge Maple | *Acer campestre* |
| Holly | *Ilex Aquifolium* |
| Oak | *Quercus robur* |
| Service Tree | *Pyrus torminalis* |
| Spindle Tree | *Euonymus europaeus* |
| White Beam | *Pyrus aria* |
| Willow | *Salix caprea* |
| Yew | *Taxus baccata* |

**Climbers**

| | |
|---|---|
| Black Bryony | *Tamus communis* |
| Bramble | *Rubus fruticosus* |
| Bush Vetch | *Vicia sepium* |
| Clematis | *Clematis vitalba* |
| Greater Bindweed | *Calystegia sepium* |
| Honeysuckle | *Lonicera Periclymenum* |
| Ivy | *Hedera Helix* |
| White Bryony | *Bryonia dioica* |
| Wild Rose | *Rosa canina* |
| Woody Nightshade | *Solanum Dulcamara* |

**Herbs**

*Abundant Species*

| | |
|---|---|
| Bluebell | *Scilla non-scripta* |
| Coltsfoot | *Tussilago Farfara* |
| Creeping Buttercup | *Ranunculus repens* |
| Germander Speedwell | *Veronica Chamaedrys* |
| Ground Ivy | *Nepeta Glechoma* |
| Jack-by-the-Hedge | *Sisymbrium Alliaria* |
| Primrose | *Primula vulgaris* |
| Red Campion | *Lychnis dioica* |
| Red Dead-nettle | *Lamium purpureum* |
| Shepherd's Purse | *Capsella Bursa-pastoris* |
| Thistle | *Carduus arvensis* |
| Toadflax | *Linaria vulgaris* |
| Violet | *Viola canina* |
| White Dead-nettle | *Lamium album* |
| Wild Chervil | *Anthriscus sylvestris* |
| Wild Strawberry | *Fragaria vesca* |

*Frequent Species*

| | |
|---|---|
| Angelica | *Angelica sylvestris* |
| Burdock | *Arctium Lappa* |
| Chickweed | *Stellaria media* |
| Cinquefoil | *Potentilla reptans* |
| Clover | *Trifolium repens* |

**Herbs** (*continued*):

*Frequent Species (contd.)*

| | |
|---|---|
| Common Daisy | *Bellis perennis* |
| Dandelion | *Taraxacum Dens-leonis* |
| Dock | *Rumex Acetosa* |
| Foxglove | *Digitalis purpurea* |
| Greater Celandine | *Chelidonium majus* |
| Hawkbit | *Leontodon hispidus* |
| Hawkweed | *Hieracium vulgatum* |
| Hedge Woundwort | *Stachys sylvatica* |
| Hogweed | *Heracleum Sphondylium* |
| Knapweed | *Centaurea nigra* |
| Lady's Smock | *Cardamine pratensis* |
| Lesser Celandine | *Ranunculus Ficaria* |
| Nipplewort | *Lapsana communis* |
| Plantain | *Plantago lanceolata* |
| Ragwort | *Senecio Jacobaea* |
| Splashed Dead-nettle | *Lamium maculatum* |
| Stinging Nettle | *Urtica dioica* |
| Stitchwort | *Stellaria Holostea* |
| Teasel | *Dipsacus sylvestris* |
| Tufted Vetch | *Vicia Cracca* |
| Wild Arum | *Arum maculatum* |
| Yarrow | *Achillea Millefolium* |

*Locally Abundant*

| | |
|---|---|
| Kingcup | *Caltha palustris* |

*Occasional Species*

| | |
|---|---|
| Agrimony | *Agrimonia Eupatoria* |
| Bladder Campion | *Silene Cucubalus* |
| Dog's Mercury | *Mercurialis perennis* |
| Figwort | *Scrophularia nodosa* |
| Fleabane | *Pulicaria dysenterica* |
| Herb Robert | *Geranium Robertianum* |
| Mallow | *Malva sylvestris* |
| Mullein | *Verbascum Thapsus* |
| Periwinkle | *Vinca minor* |
| Scentless Mayweed | *Matricaria inodora* |
| Wood Sorrel | *Oxalis acetosella* |
| Yellow Dead-nettle | *Lamium Galeobdolon* |

*Rare Species*

| | |
|---|---|
| Early Purple Orchid | *Orchis mascula* |

## X

## THE PONDS

AS long ago as 1902 efforts were made to have a pond in the botany gardens, but difficulties arose, and permission was not then given.

In 1903 a specially constructed tank was made for water plants in the new botany laboratory. Miniature bogs were made in the tank. Two trays, 4½ in. deep, and perforated at the base, were filled with peat. Each was supported on four legs and the level of the trays was adjusted by screws so that the trays could be touching the water, or out of the water.

In spite of the above arrangements the need for a pond in the garden was still felt, and it was the first addition to the botany gardens after the Board of Education grant in 1912 was given.

**Construction of first pond.** Inquiries were made and visits were paid to various parks and gardens, and it was soon realized that it was not advisable to have the pond lined with cement, as in winter cement often cracks. The soil in most parts of the botany gardens was stiff London clay, a fact that had often been deplored, but in the construction of the pond the presence of clay was an advantage.

The dimensions suggested for the pond were length 34 ft., width 23 ft. Soil was removed to the depth of 2 ft. 6 in. in the middle, and the ground was sloped gradually up to the edge. The clay in the middle of the pond was puddled and nothing added, but on the sloping sides stiff clay from elsewhere was put and well puddled.

The pond was made in 1913, and the puddled clay has stood the test of time exceedingly well.

In order to prevent the water in the pond becoming stagnant and offensive, water was brought in pipes from the nearest source, and the supply regulated by two taps. One tap was beneath the surface of the pond, and opposite to it was put a hinged flap, edged with rubber, covering the entrance to a wide outlet pipe. This arrangement was made so that when the tap was turned and the flap put back there should be a current

of water across the pond. The other tap was above the level of the water, so that a hose could be fitted on it, and sprays of water sent to sweeten the surface of the pond. It was high enough to allow of cans being filled under it.

Some arrangement was necessary to deal with drainage from the pond. There happened to be a soak-pit at a distance of 240 ft., and 'land drainage' was arranged for the greater part of the distance: pipes were placed end to end but not connected. In the neighbourhood of the pond, however, the pipes were socketed. In many gardens the surplus water would not have to be carried so far, and this item in the expense would be less.

This oval-shaped pond was surrounded by a grass verge, and outside the verge a path of old York paving-stones 3 ft. wide. By mistake the stones were cemented, and it was some time before small plants established themselves between them.

Four beds roughly triangular in shape were made near the pond.

**Freshwater marshes** were made in two of the beds. The whole water garden is at a much lower level than the adjoining part, and when rain falls water flows down the banks into the freshwater marshes and the pond. When there is not sufficient rain to keep the soil of the freshwater marshes wet the tap under the surface of the water can be turned on; the water from the pond then overflows and some goes into the adjacent parts. Sometimes in dry weather a hose is fitted on the tap above the pond and connected with a sprinkler, and the soil in the freshwater marshes is thus kept wet.

The soil to the depth of 12 in. was taken away from the other two beds. In one of these beds soil from a salt marsh on the east coast was put (see Chapter XII). The fourth bed near the pond was planned to represent a peat bog and peat bought from a horticultural firm was put in it.

Estimates for the whole of the above work were submitted by various firms, but some horticultural firms did not wish to undertake the work without supplying the plants, and finally an estimate from a local builder was accepted, and navvies did the work, the construction of the pond being always under the supervision of the botany department.

The cost of the construction, exclusive of stand-pipe and tap

for hose, was £27.[1] This did not include the removal of excavated soil. After the pond was made it was found advisable to have some stone steps in the bank leading down to the pond. The cost of the steps was £1.

In planning the pond we were greatly helped by Mr. Hales, Curator of the Chelsea Physic Gardens.

**Construction of the small pond.** As the bigger plants grew and increased in number in the pond they crowded out small

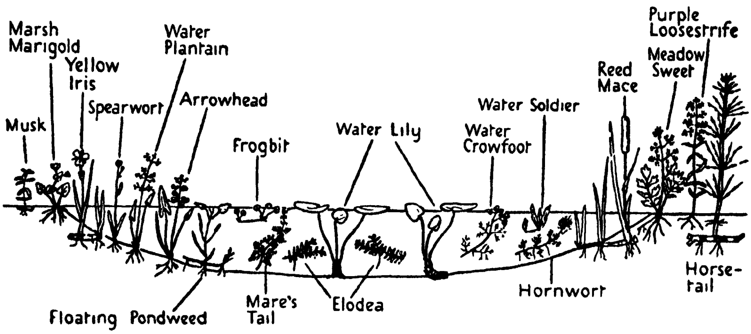



FIG. 30. Transect of Pond. James Allen's Girls' School. (E. M. Delf)

plants such as frogbit, milfoil, and water violet. In 1917 an attempt was made to reserve a place for the smaller plants. On one side of the pond an enclosure was made. Wire-netting (mesh ½ in.), supported by iron pipes, was extended from the bottom of the pond to the surface of the water, and touched the edge of the pond in two places. Many plants, such as 'bulrushes' and *Sparganium*, were removed from the enclosure thus made.

Small water plants were put in the part enclosed by the wire-netting and flourished for a time. But gradually the big plants encroached. Some plants, as water-lilies, sent stems under the ground, thus avoiding the wire-netting, and made new plants in the 'bay' or enclosure. In a few years in spite of pulling up hundreds of *Sparganium* plants, bulrushes, and reeds, the 'bay' was choked with big plants.

In 1921 it was decided to make a smaller pond and not have in it any of the larger plants that had at times almost choked

[1] Cost of stand-pipe and tap for hose was £1.

the big pond. It was arranged that the new pond should be near the first pond so that the same water-supply would be available and the same drainage. In planning the new pond the presence of big hawthorn bushes complicated matters, as it was not wished to cut them down. Finally, it was decided to make the pond of a horseshoe shape and allow a piece of land to jut into it (see frontispiece).

Puddled clay was used, as in making the bigger pond, but the expense was increased by the drought of 1921 occurring when the clay had been puddled, and no water was allowed to go into the pond. Finally, the water authorities gave permission for the pond to be filled. But by this time some of the clay had dried so much that it had to be replaced.

It was desired to have a stone path round the second pond, but the price of paving-stones had increased so much that it was out of the question.

After the pond had been made the sloping grass between the two ponds was found so slippery after rain that a stone path with steps was made. This time it was seen that the 'joints' between the stones were open and not cemented.

SUBMERGED PLANTS*

| | |
|---|---|
| Canadian Water Weed | *Elodea canadensis* |
| Hornwort | *Ceratophyllum demersum* |
| Pondweed, Curly | *Potamogeton crispus* |
| Pondweed, Shining | *Potamogeton lucens* |
| Water Soldier (winter) | *Stratiotes aloides* |
| Water Violet | *Hottonia palustris* |

PARTLY SUBMERGED PLANTS*

| | |
|---|---|
| Frogbit | *Hydrocharis morsus-ranae* |
| Limnanth, Common | *Limnanthemum nymphaeoides* |
| Mare's Tail | *Hippuris vulgaris* |
| Pondweed, Floating | *Potamogeton natans* |
| Water Crowfoot | *Ranunculus aquatilis* |
| Water-lily, White | *Nymphaea alba* |
| Water-lily, Yellow | *Nuphar luteum* |
| Water Milfoil | *Myriophyllum vulgatum* |
| Water Persicaria | *Polygonum amphibium* |
| Water Plantain, Floating | *Alisma natans* |
| Water Starwort | *Callitriche verna* |
| Water Soldier (summer) | *Stratiotes aloides* |

* In most water plants the flowers open above the surface of the water.

## MARGINAL PLANTS

| | |
|---|---|
| Arrowhead | *Sagittaria sagittifolia* |
| Bog Bean | *Menyanthes trifoliata* |
| *Brooklime | *Veronica Beccabunga* |
| Bulrush (True) | *Scirpus lacustris* |
| Branched Bur-reed | *Sparganium ramosum* |
| Codlins and Cream | *Epilobium hirsutum* |
| Flowering Rush | *Butomus umbellatus* |
| Gipsywort | *Lycopus europaeus* |
| *Horsetail | *Equisetum maximum* |
| *Iris, Yellow | *Iris Pseudacorus* |
| *Marsh Marigold | *Caltha palustris* |
| Marshwort, Procumbent | *Apium nodiflorum* |
| Musk | *Mimulus luteus* |
| *Meadow-sweet | *Spiraea Ulmaria* |
| Pickerel Weed | *Pontederia* |
| *Purple Loosestrife | *Lythrum Salicaria* |
| *Reed, Common | *Phragmites communis* |
| Reed Mace, Great | *Typha latifolia* |
| *Rush, Common | *Juncus communis* |
| Scirpus, Creeping | *Scirpus palustris* |
| Skullcap, Greater | *Scutellaria galericulata* |
| *Spearwort, Greater | *Ranunculus Lingua* |
| *Speedwell, Marsh | *Veronica scutellata* |
| Speedwell, Water | *Veronica Anagallis* |
| Sweet Flag | *Acorus Calamus* |
| *Umbrella Plant | *Cyperus longus* |
| Water Dock, Great | *Rumex Hydrolapathum* |
| *Water Mint | *Mentha aquatica* |
| Water Forget-me-not | *Myosotis palustris* |
| Water Plantain | *Alisma Plantago* |

* Growing also in freshwater marshes.

## PLANTS OF FRESHWATER MARSHES

Plants marked * in list of Marginal Plants and

| | |
|---|---|
| Alder | *Alnus glutinosa* |
| Bistort, Snake's | *Polygonum Bistorta* |
| Brook-weed | *Samolus Valerandi* |
| Creeping Jenny | *Lysimachia Nummularia* |
| Globe Flower | *Trollius europaeus* |
| Golden Saxifrage | *Chrysosplenium oppositifolium* |
| Marsh Bedstraw | *Galium palustre* |
| Marsh Cinquefoil | *Potentilla palustris* |
| Marsh Gentian | *Gentiana Pneumonanthe* |
| Marsh Orchid | *Orchis latifolia* |
| Marsh Pea Vetchling | *Lathyrus palustris* |
| Marsh Pennywort | *Hydrocotyle vulgaris* |

| | |
|---|---|
| Meadow Rue | *Thalictrum flavum* |
| Ragged Robin | *Lychnis Flos-cuculi* |
| Royal Fern | *Osmunda regalis* |
| Rush, Twisted | *Juncus spiralis* |
| Sedge, Pendulous | *Carex pendula* |
| Spearwort, Lesser | *Ranunculus Flammula* |
| Water Avens | *Geum rivale* |
| Water Parsnip | *Sium angustifolium* |
| Yellow Loosestrife | *Lysimachia vulgaris* |

### PLANTS OF THE SALT MARSH

The soil from the salt marsh on the east coast consisted of sods containing the following characteristic plants:

| | |
|---|---|
| Marsh Samphire | *Salicornia herbacea* |
| Sea Lavender | *Statice Limonium* |
| Sea Manna Grass | *Glyceria maritima* |
| Sea Orache | *Atriplex portulacoides* |

Additional plants were obtained from other salt marshes (see Chap. XII). The plants were watered with salt solution.

### THE PEAT BOG

The plants did not thrive at first in the peat bog near the pond and in 1918 the bog was re-made.

1. The peat that had been obtained from a horticultural firm was removed.
2. Stiff clay was put on the bottom and sides of the bed and was well puddled.
3. Peat from a bog in Lancashire was placed in the bed.

It was felt that the hard London water was not good for bog plants and rain water was used in watering the plants.

Plants characteristic of peat bogs, such as sundew and bog pimpernel, thrived after the above alterations had been made.

For the list of plants growing in the peat bogs see Chapter XI.

### COLONIZATION OF STONE PATH

The following planted themselves in the crevices in the stone path round the pond.

| | | |
|---|---|---|
| Bittercress | Gipsywort | Meadow Buttercup |
| Clover | Grass, Meadow | Meadow-sweet |
| Daisies | Iris, Yellow | Plantain |
| Fool's Parsley | Marsh Marigold | Purple Loosestrife |
| Forget-me-not | Marsh Pennywort | |

Later many of these were replaced by prostrate plants such as species of thyme, sandwort, &c.

### REPRODUCTION IN WATER PLANTS

It has already been shown that difficulties arose in the bigger pond owing to the rapid increase in numbers of some of the plants. Clearings have to be made at intervals, or the pond would become choked. Various methods have been tried. The most successful has been to put on wading boots, go into the pond, and pull up the superfluous plants by their underground or under-water stems, which in most cases connect numbers of plants. The plants thus removed are often most useful in the laboratory, every member of a class being able to have a plant when studying its structure and drawing it. The surplus algae, and other small floating plants, near the edge of the pond are removed by hand, and those farther in the pond by rakes with long handles, such as hay rakes. An 'umbrella plant' (*Cyperus longus*) of which another name is 'galingale', unfortunately put in the pond, not only made many plants where it was planted at the edge of the pond, but numbers of plants appeared in the freshwater marsh 33 ft. away, and in the 'order' beds at a distance of 74 ft. At last it was decided to remove the original plant, but such a big hole had to be made in the bank of the pond when the plant was taken out, that a man stood by with puddled clay and filled in the gap immediately—cost 14*s*.

The multiplication of plants in the freshwater marshes also has been great. Eight yellow iris plants were put in the freshwater marshes in 1913. Five years after, 201 iris plants were removed from one marsh alone in one morning and numbers were left.

The great increase in numbers of plants in the ponds and marshes has its advantages as well as its drawbacks. Yellow iris plants are valued not only on account of their beauty, but for their usefulness when pollination experiments are being made.

The number of purple loosestrife plants was originally only two, but hundreds have appeared in the freshwater marshes and round the edges of the pond, greatly adding to the beauty of the water garden which is such a marked feature of the botany gardens in June and July.

When the small pond was made not a single water plantain was put in it but scores soon appeared. It is thought that seeds

may have been borne by the water that came from the big pond into the little, or possibly have been introduced with other plants.

Three greater spearwort plants were put in the new pond. Those in the old pond had not increased greatly in number, but in the new pond they increased so rapidly that numbers had to be removed and still they are a danger. The flowers are so large and beautiful it seems a pity to take out the plants but it has to be done.

These details are given so that others may profit by our experience. Better ponds could be made now at Dulwich when so much experience has been gained.

Plants to be avoided when stocking a pond:

Branched Bur-reed
Common Reed
'Bulrush' (Reed Mace)
'Umbrella Plant' (Galingale)
Water Dock.

SOME RECORDS OF REPRODUCTION IN WATER AND MARSH PLANTS

| *Name of plant* | *Number planted* | *Number removed* | *Period* |
|---|---|---|---|
| | | | years |
| Branched Bur-reed | 2 | 4,987 | 15 |
| Bulrush | 1 | 59 | 9 |
| Common Reed | 1 | 1,369 | 9 |
| Reed Mace (often called Bulrush) | 6 | 127 | 13 |
| 'Umbrella Plant' | 1 | 650 | 4 |
| Water Plantain | None in small pond | 92 | 3 |
| Greater Spearwort | 3 | 1,285 | 6 |
| *Horsetail | 6 | 457 | 5 |
| Pendulous Sedge | | 1,974 | |
| Purple Loosestrife | 2 | None removed<br>271 plants | 13 |
| Soft Rush | 1 | 314 clumps | 4 |
| Yellow Iris | 8 | 865 | 6 |

* Numbers removed not counted for some years.

SOME CONDITIONS UNDER WHICH WATER-PLANTS LIVE

**Comparison of temperatures of water in pond and air outside pond.** A thermometer registering maximum and mini-

mum temperatures was fastened under the water in the large pond, and a similar thermometer was placed in the air outside the pond on a branch of a tree nearly above the submerged one. Readings of the thermometers were, and are still being taken, in and out of school hours by various girls in the class studying water plants. Readings are rarely taken in the holidays. Frost, for varying periods in three years, prevented readings of the thermometer in the pond being noted. (In one year the pond was frozen for twenty-four consecutive days, and when the ice melted the thermometer was found to be broken.)

RECORDS OF TEMPERATURE OF WATER IN POND (A) AND AIR OUTSIDE POND (B)

| | *No. of days on which readings taken* | *No. of days on which max. temp. of A lower than that of B* | *Percentage* | *No. of days on which min. temp. of A higher than that of B* | *Percentage* |
|---|---|---|---|---|---|
| 1st year | 65 | 62 | 95·4 | 62 | 95·4 |
| 7 years | 250 | 233 | 93·2 | 242 | 96·8 |
| 12 years | 440 | 408 | 92·7 | 386 | 87·7 |

The readings of the maximum and minimum thermometers in the pond and in the air outside the pond taken during (1) July of one year, and (2) June of another year were as follows:

| *Date* | *Maximum temperature* | | *Minimum temperature* | |
|---|---|---|---|---|
| | *In pond* | *In air outside* | *In pond* | *In air outside* |
| | ° F. | ° F. | ° F. | ° F. |
| (1) July 1 | 79 | 90 | 60 | 54 |
| ,, 2 | 76 | 84 | 57 | 47 |
| ,, 3 | 80 | 87 | 58 | 49 |
| ,, 4 | 84 | 91 | 60 | 51 |
| ,, 7 | 78 | 85 | 61 | 49 |
| ,, 8 | 76 | 88 | 57 | 48 |
| ,, 9 | 79 | 84 | 60 | 52 |
| ,, 10 | 79 | 84 | 61 | 51 |
| ,, 11 | 77 | 81 | 58 | 55 |
| ,, 14 | 81 | 90 | 64 | 55 |
| ,, 15 | 85 | 88 | 65 | 57 |
| ,, 16 | 79 | 84 | 61 | 54 |
| ,, 17 | 76 | 82 | 58 | 52 |
| ,, 18 | 80 | 89 | 61 | 54 |

No. of days on which readings were taken = 14
,, ,, ,, max. temp. lower in pond = 14
,, ,, ,, min. temp. higher in pond = 14

| Date | Maximum temperature | | Minimum temperature | |
|---|---|---|---|---|
| | *In pond* | *In air outside* | *In pond* | *In air outside* |
| | ° F. | ° F. | ° F. | ° F. |
| (2) June 7 | 69 | 72 | 57 | 48 |
| ,, 9 | 60 | 67 | 60 | 55 |
| ,, 12 | 71 | 80 | 56 | 46 |
| ,, 13 | 69 | 78 | 56 | 48 |
| ,, 14 | 67 | 76 | 52 | 44 |
| ,, 15 | 64 | 76 | 54 | 47 |
| ,, 19 | 79 | 88 | 55 | 49 |
| ,, 20 | 68 | 80 | 58 | 52 |
| ,, 21 | 70 | 79 | 54 | 47 |
| ,, 22 | 61 | 68 | 60 | 54 |
| ,, 23 | 60 | 69 | 56 | 48 |
| ,, 26 | 60 | 69·5 | 58 | 52 |
| ,, 29 | 64 | 70 | 58 | 51 |
| ,, 30 | 62 | 71 | 55 | 49 |

No. of days on which readings were taken = 14
,, ,, ,, max. temp. lower in pond = 14
,, ,, ,, min. temp. higher in pond = 14

SUMMARY OF READINGS OF MAXIMUM AND MINIMUM THERMOMETERS IN MAY

No. of days on which readings were taken = 16
,, ,, ,, max. temp. lower in pond = 16
,, ,, ,, min. temp. higher in pond = 16

The above readings show that generally the maximum temperature of the water is lower than that of the air above it and the minimum temperature higher, that is the temperature of the water does not show such extremes of temperature as the air. The girls see that water plants live under more uniform conditions of temperature than land plants.

**The beauty of the ponds and marshes.** In the summer the ponds are not only interesting to biologists, but attractive to all on account of their great beauty. The water-lilies, water soldiers, and water plantains in flower in the deeper part, the wealth of colour afforded by the purple loosestrife, yellow loosestrife, and meadow-sweet, and the background of royal ferns, bulrushes, and reeds, make a picture not easily forgotten.

## ANIMALS OF THE POND

The ponds are as valuable for the study of animals as for the study of plants. In the ponds and marshes are numbers of frogs,

toads, newts, pond skaters, water boatmen, great water beetles, pond snails (trumpet and spiral), sticklebacks, water fleas, fresh-water shrimps, caddis fly larvae, and larvae of dragon flies. With the exception of some water snails put in the pond in 1913 for the purpose of checking the growth of algae, and two newts in the same year, no animals have been put in the pond. They have come in by themselves.

Probably the eggs of some have been introduced on the leaves of plants. Frogs and toads often pay visits to a pond from a distance. In the winter in the J.A.G.S. pond, as in other ponds, frogs bury themselves in the mud at the bottom. Water boatmen, pond skaters, and great water beetles can come from afar, as sometimes at night they rise from the pond in which they have been living, and fly to another pond and settle there.

The above animals are the regular inhabitants of the pond. There are occasional visitors. In 1924, just before the holidays, a pair of wild ducks appeared on the big pond. On the first day of the next term the duck was seen with seven ducklings. After a time the parent ducks flew away, but nearly every year a pair come to stay for a time on the ponds and marshes.

In the spring the pond seems absolutely full of frogs and frog spawn and afterwards tadpoles. Later, tiny frogs can be seen leaving the pond, and some are met at a considerable distance making their way to yet more distant parts.

With ponds so accessible it is easy for girls to study the life-histories of animals. It is fascinating to watch the various pond animals, and girls have been enthralled at actually seeing the metamorphosis of dragon flies.

To-day I saw the dragon fly
Come from the wells where he did lie,
An inner impulse rent the veil
Of his old husk: from head to tail
Came out clear plates of sapphire mail.
He dried his wings; like gauze they grew;
Thro' crofts and pastures wet with dew,
A living flash of light he flew. TENNYSON.

# XI

# THE HEATH AND THE BOG IN THE HEATH

## THE HEATH

THE soil in two small pieces of ground, each about 12 ft. by 5 ft., was trenched in 1905, some was taken away and soil from a heath put in its place.

Typical heath plants such as heather, fine-leaved heath, and sheep's fescue grass grew well in the heath soil. These plots were convenient as they were just outside the laboratory, and for nine years heath plants were studied in them; but they were very small. In 1912 a piece of ground 100 ft. long, 40 ft. broad at one end and 24 at the other, was set aside for a heath in the new field. The ground was trenched two spits deep in 1914, the grass was buried at the bottom, and the subsoil was kept in its original position. The cost of the above work was £9 15*s*. Soil was brought from a heath in Surrey. The cost (carriage in cluded) in 1914 was £1 a load. In 1933 it was £1 10*s*. a load.

The roots of heather and heath plants are invaded by fungal threads, the association between the roots and the fungus being called a mycorrhiza. Cells of the root digest the hyphae. Seedlings of heather and heath do not develop properly unless the fungus is present. This shows why it is so important to have soil from a heath when trying to grow heather and other heath plants.

## SUPPLY OF PLANTS

The following were ordered from a plant nursery near a heath:

200 heather plants
100 fine-leaved heath plants
200 whortleberry plants.
100 bramble plants
100 gorse plants
 24 yarrow plants.

Some of the plants were delayed on the railway owing to the war, and arrived in a bad condition. Few of the gorse plants lived. The number of plants supplied the first year seemed

large, but it was quite inadequate to populate the heath. Nearly every year since the heath was made, typical heath plants from various parts of the country have been put in it. At one time parts of the heath represented heaths in different regions of Britain. The plants had come from a Yorkshire heath, two Kent heaths, and two heaths in Scotland. The year after the soil was brought typical heath plants appeared which had not been planted, so presumably the seeds were in the soil. The plants (tormentil, sheep's fescue grass, and heath bedstraw) appeared in groups.

**Gorse.** It was found more satisfactory to sow gorse seeds in pots and put out the young plants, than to transfer larger plants. When the gorse was established many young seedlings were found. After a time the gorse bushes had to be cut back.

**Bracken.** For many years there had been difficulty in transplanting bracken. The plants often died. The advice of a Director of a well-known park was to take a yard of soil with each plant. Bracken plants were given to the school from the park, but it was necessary to send a cart as so much soil was removed with the plants. The plants lived.

**Bramble.** At first bramble was kind in covering bare places, but it grew so rapidly it had to be cut back in 1917, 1919, 1920, and other years.

**Heath grasses.** Plants not characteristic of heaths had to be removed, and often bare patches were left. Seed of typical heath grasses (sheep's fescue and wavy hair grass) was obtained from a firm specializing in grasses, and sown. The result was most satisfactory.

**Heather.** Heather is not easy to transplant but plants can be grown from cuttings.

**Struggle of heath plants with aliens.** Meadow and couch grass at first were great foes and a few months after the heath was made the heath plants were almost choked by them.

As in the case of the wood, girls of other forms came to the rescue of those in charge, and by the end of the first year the

heath seemed clear of these grasses. But it was only clear for a time and there was a constant battle for many years.

During the first year also, a struggle with groundsel occurred but the groundsel was more easily exterminated. Creeping buttercup, clover, dock, and thistles were other troublesome weeds until the heath plants were well established, but they were not so persistent as the grasses.

**Transpiration in heath, moorland, and bog plants.** For many years it was believed that heath, moorland, and bog plants had restricted transpiration, not on account of the scarcity of water, but because the water contained toxins, or poisons.

Schimper, in 1898, when considering the small leaves and protected stomates seen in many heath and bog plants, characters usually associated with plants which have restricted transpiration, concluded that these plants lived under conditions of 'physiological drought': that toxins were present in the soil. This theory held sway for years. In 1918 Montford showed by work on cotton grass that there was no 'physiological drought' in a bog. He showed by experiments that the water of moorland soils was not poisonous to moorland plants, and that absorption and transpiration of water go on freely.[1]

In 1923 Stocker found that, although individual leaves in heather and cross-leaved heath are small, the plants have not a reduced leaf area in relation to the absorbing surface of the roots, that transpiration is not restricted, and that the plants do not live under conditions of 'physiological drought'.

PLANTS OF THE J.A.G.S. HEATH

| | | |
|---|---|---|
| Dominant | Heather | *Calluna vulgaris* |
| Dominant | Fine-leaved heath | *Erica cinerea* |
| | Bramble | *Rubus fruticosus* |
| | Bracken | *Pteris aquilina* |
| | Wavy Hair Grass | *Deschampsia flexuosa* |
| | Sheep's Fescue Grass | *Festuca ovina* |
| | Broom | *Cytisus scoparius* |
| | Gorse | *Ulex europaeus* |
| | Yarrow | *Achillea millefolium* |
| | Whortleberry | *Vaccinium Myrtillus* |

[1] See also Chapter XII. Dr. Delf's work on Transpiration in Salt Marsh plants.

| | |
|---|---|
| Wood Sage | *Teucrium Scorodonia* |
| Harebell | *Campanula rotundifolia* |
| Tormentil | *Potentilla Tormentilla* |
| Mountain groundsel | *Senecio sylvaticus* |
| Eyebright | *Euphrasia officinalis* |
| Bird's-foot Trefoil | *Lotus corniculatus* |
| Devil's Bit Scabious | *Scabiosa succisa* |
| Hair Moss | *Polytrichum* |
| Sheep's Sorrel | *Rumex Acetosella* |
| Club Moss | *Lycopodium clavatum* |
| Cornish Heath | *Erica vagans* |
| Heath Bedstraw | *Galium saxatile* |
| Bilberry | *Empetrum nigrum* |
| Milkwort | *Polygala vulgaris* |
| Sheep's Bit | *Jasione montana* |
| Bent-grass | *Agrostis canina* |
| Lady's Tresses | *Spiranthes spiralis* |
| Ciliated Heath | *Erica ciliaris* |
| St. Dabeoc's Heath | *Dabeocia polifolia* |
| St. Keverne Heath | *Erica vagans. var. St. Keverne* |
| Mackay's Heath, Crawford's variety | *Erica Mackayi. flore pleno* |

### THE BOG

It was decided in 1916 to have, in the heath, a bog much bigger than the one near the pond. The contour of the heath showed a natural basin-like shallow depression near the middle, towards the back. This depression was made deeper, and a narrow part 4½ ft. wide was made running into it from the front. To prevent the water draining away, when the hollow and narrow part were filled with peat, the bottom and sides were lined with puddled clay.

An estimate for preparing the ground for the new bog and redigging and repuddling the small bog was £3 13*s.* 0*d.* It was accepted.

When the soil was taken away the precious top spit was spread over other parts of the heath.

**Provision of peat.** Peat straight from a peat bog was thought to be the most satisfactory way of obtaining it. Professor Bottomley, who was at the time conducting experiments on peat, kindly promised that some from a bog in Lancashire should be sent free, except for the expense of labour (digging the peat and packing it in sacks) and carriage.

The area of the big and little bogs is 234 square ft., and it was first arranged that that extent of peat should be dug from a depth of 2 ft., but, on account of expense, it was altered to a depth of 1½ ft.

Samples of peat were sent. On December 8th, 1916, an order for 6½ tons of peat from the *Sphagnum* patches of the bog was given, but it did not come for seven months. The delay had been caused by the peat having been frozen for two months, by shortage of railway wagons, and by difficulty of obtaining labour. The peat arrived in July 1917 and proved to be cotton grass peat as well as *Sphagnum.* It was put in the two places prepared for it.

After the big bog was made, the soil round it, which had suffered while the bog was being made, was trenched, and 2½ loads of heath soil were added to it.

**Water for the bog.** In case there should not be sufficient rain at any time to keep the peat wet, water is brought in a pipe to a part of the heath near the bog, and the bog can be flooded by a hose. Unfortunately it is not possible to use rain-water for the whole bog. Plants newly put in are sometimes watered with rain-water to give them a good start.

**Plants of the bog.** Bog plants, with the exception of *Sphagnum,* thrived in the new bog. Cross-leaved heath formed conspicuous patches, bog myrtle grew well, creeping willow, pistillate and staminate, soon flowered, bog pennywort spread rapidly. Cotton grass also flourished and when in fruit, with its nodding white plumes, gave a characteristic look to the bog. Grass of Parnassus flowered, sundews lived and in one year survived the winter, four butterworts also lived through a winter and three seedlings were found.

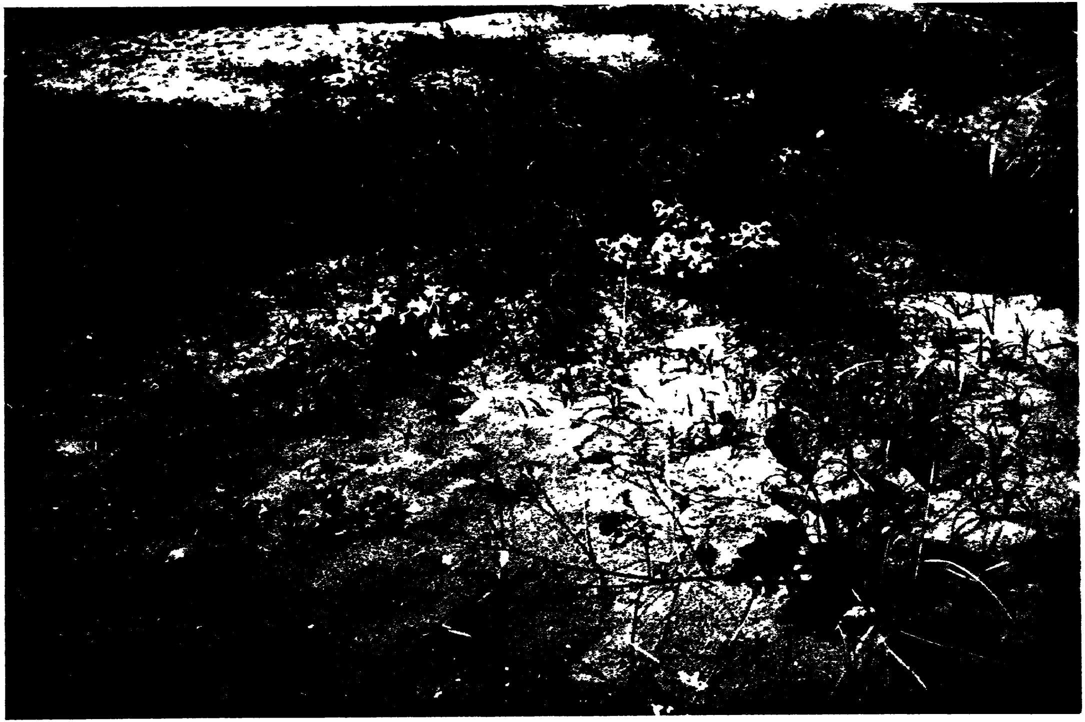
*Sphagnum,* sent from various bogs in England and Scotland, has never been grown successfully at Dulwich. Year after year it has been planted. Sometimes it has been put right in the peat, at other times it has been put in a dish and the dish put in the peat. It has been kept wet with rain-water but it has never formed a sheet.

**Thinning of plants.** The rushes spread very quickly and after a time so many plants had to be removed that the roots

of those taken up were washed to save the peat. Cotton grass also had to be removed and hundreds of marsh pennywort plants. The willows were cut back.

PLANTS OF THE J.A.G.S. BOGS

| | |
|---|---|
| Cross-leaved Heath | *Erica tetralix* |
| Marsh Pennywort | *Hydrocotyle vulgaris* |
| Bog Myrtle | *Myrica Gale* |
| Blue Moor Grass | *Molinia caerulea* |
| Bent Grass | *Agrostis canina* |
| Cotton Grass | *Eriophorum vaginatum* |
| Heath Rush | *Juncus squarrosus* |
| Soft Rush | *Juncus effusus* |
| Sharp-flowered Jointed Rush | *Juncus acutiflorus* |
| Lesser Jointed Rush | *Juncus supinus* |
| Sedges | *Carex sp.* |
| Bog Asphodel | *Narthecium ossifragum* |
| Creeping Willow | *Salix repens* ♂ and ♀ |
| Lesser Spearwort | *Ranunculus flammula* |
| Marsh Bird's-foot Trefoil | *Lotus uliginosus* |
| Bog Moss | *Sphagnum compactum* |
| Bog Pimpernel | *Anagallis tenella* |
| Marsh St. John's Wort | *Hypericum elodes* |
| Marsh Andromeda | *Andromeda polifolia* |
| Sundew, Round-leaved | *Drosera rotundifolia* |
| Sundew, Long-leaved | *Drosera longifolia* |
| Sundew, Intermediate | *Drosera intermedia* |
| Butterwort, Common | *Pinguicula vulgaris* |
| Butterwort, Large-flowered | *Pinguicula grandiflora* |
| Grass of Parnassus | *Parnassia palustris* |
| Bog Gentian | *Gentiana Pneumonanthe* |
| Marsh Red Rattle | *Pedicularis palustris* |
| Marsh Club-moss | *Lycopodium inundatum* |



(*Photo Elliott & Fry*)

FIG. 32. 1922. Colonization of Sand Dune by one Sand-sedge plant planted in 1920. Sea-holly plants also shown

# XII

# SAND DUNES—SALT MARSHES—PEBBLE BEACH

## SAND DUNES

THE first sand dune in the botany gardens was made in 1907. The sand was sent from Lowestoft by the Great Eastern Railway. A number of typical plants from sand dunes thrived in it, and it proved very useful, but the dune was a very small one, and when more land was available for botany gardens it was decided that, among other things, a larger sand dune should be made.

In 1919 it was found that sea sand could not be obtained in the same way as before, and many inquiries were made elsewhere. The chief difficulty was the delivery at the school. The railways would convey it to London, but the goods depots were usually some way from Dulwich, and the cartage would add considerably to the cost. However, after seeing a sample from Brighton, it was agreed that the sand should be sent to East Dulwich station. The school authorities had it carted from the station.

*Cost.* The price of the sand steadily increased as the years went on. In 1915 it was 5*s.* 10*d.* a ton delivered at East Dulwich, in 1919 8*s.* 3*d.*, in 1920 10*s.* 6*d.*, in 1923 11*s.* 10*d.*, and in 1933 the price was 12*s.* 3*d.*

The length of the piece of ground allotted to the new sand dune was 31 ft., and the width 23 ft. at one end and 18 ft. at the other end. In January 1920, 7½ tons of sand were put on the site, and spread over the ground. The amount of sand seemed so inadequate that 6 more tons were obtained, and then 9 tons, making a total of more than 22 tons. The last consignment of sand was piled up in places to imitate dunes.

In 1923 the sand dune was enlarged and 8 additional tons of sand were put on it.

During the first year of the dune (1920) various plants, such as sand sedge, sand lyme grass, sea holly, sea stork's bill, viper's bugloss, and biting stonecrop, were put in it, and thrived. Other plants, such as groundsel, yarrow, and toadflax, not

characteristic of sand dunes, thrived also, and when uprooted were found to have unusually long roots.

In 1921 one buck's-horn plantain appeared, and by means of seeds gave rise to many new plants. In 1922, 6,614 plantain plants were removed, and in three years a total of 12,563.

The rate of reproduction of sand sedge was even more rapid. By design only one sand sedge plant, planted in 1920, was allowed to develop, so that the rate of reproduction could be noted. The one plant gave rise to so many other plants, that, in four years, more than 22,000 were removed, and about 7,000 were still left in the dune.

The process of colonization was clearly seen. From the one original sand sedge plant straight rows of other plants appeared, and steadily grew in length, appearing like columns invading a territory. The photograph (Fig. 32) taken in 1922 shows the radiating appearance, but it would have shown even better if the photograph had been taken a little sooner.

Under the surface was a network of rhizomes, which helped to bind the layers of the sand, especially those near the top. In 7 years, 72,300 plants were removed, and still great numbers were left. No girl who looked after the sand dune will easily forget that sand sedge is reproduced by other means than seeds.

The figures for reproduction in sand lyme grass seem insignificant after those of sand sedge. From one plant put in the dune in 1920 more than 3,000 descendants were removed in 5 years, and 329 remained in the dune.

The sand dune soon began to look like a normal sand dune. Viper's bugloss and sea holly quickly increased by means of seeds; there was one viper's bugloss plant in 1920 and 60 plants in 1925. The long roots of viper's bugloss (10 in. long in the original plant) and the long erect underground stems of sea holly helped to give stability to the sand. A sea holly plant that was dug up at Aberystwyth and sent to the Dulwich sand dune by an 'old girl' had a vertical underground stem 35 in. long. An enormous hole had to be dug to obtain the specimen uninjured. The viper's bugloss and sea holly formed beautiful patches of colour against the leaves of sand sedge and sand lyme grass.

PLANTS OF THE J.A.G.S. SAND DUNES

| | | |
|---|---|---|
| Sand Sedge | Chief Binders | *Carex arenaria* |
| Sand Lyme Grass | | *Elymus arenarius* |
| Marram Grass | | *Ammophila arenaria* |
| Sea Couch Grass | | *Agropyron junceum* |
| Sea Kale | Other Binders | *Crambe maritima* |
| Sea Holly | | *Eryngium maritimum* |
| Sea Bindweed | | *Convolvulus Soldanella* |
| Sand Fescue Grass | | *Festuca rubra* var. *arenaria* |
| Prickly Saltwort | | *Salsola Kali* |
| Frosted Orache | | *Atriplex laciniata* |
| Sea Buckthorn | | *Hippophae rhamnoides* |
| Sand Spurge | | *Euphorbia Paralias* |
| Sea Rocket | | *Cakile maritima* |
| Sea Purslane | | *Arenaria peploides* |
| Rest Harrow | | *Ononis repens* |
| Viper's Bugloss | | *Echium vulgare* |
| Biting Stonecrop | | *Sedum acre* |
| Bird's-foot Trefoil | | *Lotus corniculatus* |
| Sand Stork's Bill | | *Erodium cicutarium* |
| Sand Spurrey | | *Spergularia rubra* |
| Burnet Rose | | *Rosa spinosissima* |
| Dog's-tooth Grass | | *Cynodon Dactylon* |
| Wormwood sp. | | *Artemisia Stelleriana* |

### THE SALT MARSHES

A small salt marsh was made in 1905. Great difficulty was experienced in obtaining the soil. Finally, a visit was paid to a salt marsh near Gravesend, some soil was put into sacks, and the sacks sent by train to Dulwich. When the sacks were emptied in the botany gardens, the contents, slimy mud in which were fragments of plants, looked most unpromising. But the marsh proved a great success.

After making many experiments the girls concluded that the best solution to be used in watering the plants was one containing 2 per cent. of salt. Tidman's sea salt was used at first, but proved expensive, and common salt was substituted.

### TRANSPIRATION IN SALT MARSH PLANTS

Many salt marsh plants are succulent, and show a reduction in leaf surface, characteristics usually associated with plants that live in dry habitats, such as members of the Cactaceae of North American deserts, and the Sedums.

For many years (1898–1911) it had been believed that these salt marsh plants were unable to absorb water freely on account of the saltness of the soil solution, and that this caused a low rate of transpiration.

In 1911 Dr. E. M. Delf, an 'old girl', published the results of her investigations on the transpiration of salt marsh plants, including results of research work at the J.A.G.S. salt marsh.[1] She had already made observations on salt marsh plants at Higham, and many visits were made to the artificial salt marsh at the school, where observations were made on the stomates of the sea aster (*Aster tripolium*) and annual marsh samphire (*Salicornia annua*), which happened to be represented by particularly flourishing plants, and on the sea blite (*Suaeda maritima*).

Dr. Delf found:

1. That two typical salt marsh plants, annual marsh samphire and sea blite, may have a high rate of transpiration per unit of surface area, even greater than plants such as dog's mercury and broad bean under similar conditions.
2. That these plants, when not already turgid, are able to absorb water freely over their whole surface.
3. That the stomates in annual marsh samphire and in sea aster are capable of opening and shutting, and are sensitive to light and to variations in humidity, contrary to statements by various previous workers.

Dr. Delf was early in the field to test by means of experiments Schimper's theory of 'physiological drought'. She found it did not hold in the case of salt marsh plants. The results of her work were incorporated in articles contributed to *Annals of Botany*. Dr. Delf was followed in the investigation of 'physiological drought' by Montford who made experiments on bog plants, and by Stocker who made experiments on heath plants (see Chap. XI).

In 1913 another salt marsh was made as the original one was small. It was arranged that soil from near Burnham-on-Crouch should be sent, but unforeseen difficulties arose, and permission from more than one authority had to be obtained before the soil could be removed. The carriage of the soil by train was

[1] 'Transpiration and Behaviour of Stomata in Halophytes', *Annals of Botany*, 1911; 'Transpiration in Succulent Plants', *Annals of Botany*, 1912. Thesis approved for D.Sc. Lond.

the chief expense. The sods when they arrived at Dulwich contained marsh samphire, sea lavender, sea orache, and sea manna grass. There was more than sufficient soil for the site chosen near the pond, and another salt marsh was made in the new piece of ground acquired by the Governors in 1912. Plants, characteristic of salt marshes, have flourished in all three marshes.

It did not seem likely, at first, that girls would take as much interest in salt marsh plants as in the more beautiful plants in the order beds, plots for pollination experiments, the wood and the pond, but it has been evident in many years that great zeal has been shown by those in charge of the salt marshes. The girls who had charge of the salt marshes were only required to water them with salt solution once a week, but they could often be seen in the dinner-hour and after school making salt solution and pouring it on the marshes. One year two girls poured 4,078 gallons on one salt marsh, using a two-gallon can and having to go a little distance for the water.

Records of ten years show that the average amount of salt solution given per year (chiefly in the summer term) was 730 gallons on one salt marsh, 480 gallons on another, and 1,107 on the largest salt marsh. Records also show that, in eight years out of ten, girls in charge of salt marshes were among those who had done the best work of the year.

Material from one of the salt marshes at J.A.G.S. is being used in research work at the time of writing. There is in a salt marsh made in 1913 a beautiful specimen of the shrubby sea blite (*Suaeda fruticosa*) which has been there for more than fifteen years. It forms a bush roughly 7 ft. in width and in 1933 the tallest branch was 4 ft. 7 in. high.

Miss Martin, of Westfield College, is publishing a paper on the two species of sea blite. She finds that the leaves from a shrubby sea blite bush at the Chelsea Physic Garden, which has had no salt, are less fleshy than those from a pebble beach at Blakeney Point and Wells (Norfolk), and that leaves from the J.A.G.S. plant, which has been watered at intervals with a 2 per cent. salt solution, are intermediate in structure, being on the whole less succulent than those from Blakeney.

In Miss Martin's paper presented at the British Association meeting at Leicester 1933, there was an account of the anatomi-

cal characters of the two species of sea blite, annual sea blite (*Suaeda maritima*) usually growing in salt marshes, and shrubby sea blite (*Suaeda fruticosa*) usually found on pebble beaches on the edges of salt marshes, and an attempt to correlate their outstanding features with the conditions of their environment.

PLANTS OF THE J.A.G.S. SALT MARSHES

| | |
|---|---|
| Marsh Samphire | *Salicornia herbacea* |
| Perennial Marsh Samphire | *Salicornia radicans* |
| Annual Marsh Samphire | *Salicornia annua* |
| Sea Plantain | *Plantago maritima* |
| Buck's-horn Plantain | *Plantago coronopus* |
| Sea Arrow Grass | *Triglochin maritimum* |
| Sea Aster | *Aster Tripolium* |
| Annual Sea Blite | *Suaeda maritima* |
| Shrubby Sea Blite | *Suaeda fruticosa* |
| Sea Manna Grass | *Glyceria maritima* |
| Thrift | *Armeria vulgaris* |
| Sea Heath | *Frankenia laevis* |
| Sea Lavender | *Statice Limonium* |
| Sea Mugwort | *Artemisia maritima* |
| Sea Milkwort | *Glaux maritima* |
| Sea Purslane | *Arenaria peploides* |
| Sea Spurrey | *Spergularia marginata* |
| Scurvy Grass | *Cochlearia danica* |
| Sea Orache | *Atriplex portulacoides.* |

In one of the salt marshes the plants were arranged in associations in the order they might be found, from the seaward side of a salt marsh to the highest zone rarely covered by the tide.

THE PEBBLE BEACH

A small pebble beach was made in 1909, but not of pebbles from the sea-shore. The foundation was sea sand from Lowestoft, and the girls brought pebbles of various sizes. Groups of sea campion, sea pink, and other plants found on pebble beaches were soon established. Although the plot was only a small one, some interesting work was done in covering the sea campion and sea pink plants with pebbles, and watching the plants as they struggled through the stones.

In 1919 it was decided to make a pebble beach, or shingle beach, next to the sand dune in the new playground, the sand dune and pebble beach to merge into one another. The



(*Photo Elliott & Fry*)

Fig. 33. General view of Pebble Beach with Sand Dune and Heath, and Wood eleven years old in distance. 1925

dimensions of the site were: length at back 24 ft., width 23 ft. at the wide end, tapering off to nothing, the front being curved.

*Construction.* Soil was removed to a depth of 1½ ft.; 12 tons of 'coarse beach' material were sent from Brighton and spread over the ground. The pebbles were piled up to a greater height at the end adjoining the sand dune, and the 'beach' was shallow at the end where it might be supposed the sea came up to the beach. More material seemed needed, so another 6 tons were obtained. It was very difficult without any previous experience of the kind to gauge beforehand the amount that would be needed.

*Cost.* The price of the first 12 tons was 8*s.* a ton, in truck loads of 6 tons and upwards delivered carriage paid at East Dulwich station. When the last 6 tons were ordered a letter was received stating that owing to the bargemen having 'gone on strike' their wages had been increased, and therefore the charge would be 10*s.* 6*d.* per ton. In 1933 the price per ton delivered carriage free at East Dulwich station was 11*s.* 6*d.*

In May 1920 yellow horned poppy, scurvy grass, sea pink, and sea campion were put in the pebble beach. When a poppy was planted some pebbles were removed, the root held in position, and a *little* soil placed round the lower part of the long root. Probably very little soil remained in position when the pebbles were put round the upper part of the root. The poppy plants flourished, and bore many flowers that summer and following summers.

It was supposed that the roots had grown downwards until they reached the soil, but when some of the pebbles were removed, some months after the poppies had been planted, in order to see what had happened, it was found that not one root was in contact with the ground, and that none of the small amount of soil that had been put with the roots was to be seen.

The yellow horned poppies that had been left in the shingle produced seeds and many young plants developed. These young plants showed their preference for easier conditions than prevail on a pebble beach by forming a line along the junction of pebbles and path, some distance from the parent plants. Some seedlings, however, developed among the pebbles.

*Imitation of Natural Conditions.* (1) From time to time some of the plants, sea campion, sea pink, and yellow horned poppy,

were subjected to the proper 'overhead treatment' characteristic of mobile shingle. They were covered, or nearly covered, with pebbles. The plants grew through the stones, and seemed more vigorous after the treatment. (2) After the pebble beach had been in existence seven or eight years some seaweed was put on the shingle every year, imitating the 'drift' that occurs in Nature. On natural sea beaches detached seaweed and other organic debris are thrown up by the waves on the beach, and these form an important source of 'humus' for the shingle-beach plants.

PLANTS OF THE J.A.G.S. PEBBLE BEACH

| | |
|---|---|
| Poppy, Yellow Horned | *Glaucium luteum* |
| Scurvy Grass | *Cochlearia officinalis* |
| Shrubby Sea Blite | *Suaeda fruticosa* |
| Sea Beet | *Beta maritima* |
| Sea Campion | *Silene maritima* |
| Sea Kale | *Crambe maritima* |
| Sea Lavender | *Statice Limonium* |
| Sea Mertensia | *Mertensia maritima* |
| Sea Pea | *Lathyrus maritimus* |
| Sea Pink | *Armeria vulgaris* |
| Sea Purslane | *Arenaria peploides* |
| Stonecrop, Biting | *Sedum acre* |

## XIII

## THE CORNFIELD. THE MEADOW. CHALK BEDS. THE WALL. MENDELIAN EXPERIMENTS. SOIL EXPERIMENTS

### THE CORNFIELD

A SMALL cornfield was made in 1902. It was useful, the girls were interested in it, and some paid visits to cornfields to obtain seeds of various 'weeds' of the cornfield: poppy, cornflower, corn-cockle, corn marigold. But the ground was wanted, and the cornfield ceased to exist.

For some years other developments more important were needed, but early in 1926 a plot of ground, 66 ft. by 10 ft., was given for a cornfield. The turf was removed, and the ground dug. In 1928 another piece of the same size, adjacent to the first, was added and a path was left between the two pieces.

**Sowing of corn.** For the first two years Yeoman King Wheat was sown in rows. In the third year the following were sown:

| | |
|---|---|
| Wheat | Red Stand Up |
| Oats | Giant Black Winter |
| Barley | Six-rowed Winter |
| Rye | Giant Star |

Wheat, oats, barley, and rye were sown in other years. With the exception of one year, this was done in the autumn term.

The crop grew well but often the harvest was spoilt by birds. In some years netting was used and proved fairly successful in protecting it.

The crop is cut each year in the late summer and the ground dug over. A dressing of superphosphate, kainit, and ammonium sulphate was given to the field one year.

**Weeds of the cornfield.** The weeds of a cornfield are mostly annuals, often introduced with impure seed. Perennials do not thrive when the soil is disturbed every year.

Dr. Brenchley, the chief botanist at the Rothamsted Experimental Station, and an 'old girl', in *Weeds of Farm Lands* states: 'The cereals form a group of plants that collectively has less

direct influence upon the weed flora than any of the other types of crops', and 'Every weed of any importance is found among all the cereals, but some are more particularly encouraged or discouraged by one or other of them'.

Typical cornfield weeds would doubtless have appeared of themselves in the cornfield made at J.A.G.S., but it might have been some time before there was a representative collection, so seeds were sown. In time the weeds thrived and began to be self-sown.

The cornfield now proves a great attraction with its rows of wheat, barley, oats, and rye, and among the corn the gay flowers of red poppies, scarlet pimpernels, corn-cockles, and heartsease.

PLANTS OF THE J.A.G.S. CORNFIELDS

| | |
|---|---|
| Red Poppy | *Papaver Rhoeas* |
| Corn-cockle | *Lychnis Githago* |
| Scarlet Pimpernel | *Anagallis arvensis* |
| Corn Buttercup | *Ranunculus arvensis* |
| Heartsease | *Viola tricolor* |
| Spurrey | *Spergula arvensis* |
| Sun Spurge | *Euphorbia Helioscopia* |
| Corn Marigold | *Chrysanthemum segetum* |
| Cut-leaved Crane's-bill | *Geranium dissectum* |
| Field Madder | *Sherardia arvensis* |
| Shepherd's Needle | *Scandix Pecten-Veneris* |
| | *Silene quinquevulnera* |

THE MEADOW

The meadow was made in two adjacent pieces of land, 50 ft. by 25 ft. and 65 ft. by 18 ft. They were dug over and a path was left between them. The following grasses were sown in 1926: crested dog's-tail, cock's-foot, meadow foxtail, Timothy, perennial rye grass, Italian rye grass, smooth meadow grass. Some typical meadow plants other than grasses were planted. The hay is cut every year.

**Plants of the meadow.** As a rule in a meadow the plants are chiefly grasses and leguminous plants, with a variety of species belonging to other families. They are nearly all perennials.

In the J.A.G.S. meadow the cock's-foot grass grew so strongly that it overpowered the finer grasses and other plants, and some clumps were removed.

Typical meadow plants and seeds of meadow plants, other than grasses, were planted in various years after the first year. Such plants have been classified as follows:[1]

A. Plants that must be regarded as weeds in all circumstances, (1) poisonous plants, (2) coarse growing plants that deteriorate the quality of the meadow, (3) plants of low feeding value, (4) parasitic weeds.
B. Plants that are considered to possess a certain feeding value, but are regarded as weeds if they are present in too great quantity.
C. Plants which are difficult to class definitely as weeds, but are noxious if present in too great abundance. Probably most are of some use as food.

GRASSES OF THE J.A.G.S. MEADOW

| | |
|---|---|
| Crested Dog's-tail grass | *Cynosurus cristatus* |
| Cock's-foot grass | *Dactylis glomerata* |
| Meadow Foxtail grass | *Alopecurus pratensis* |
| Timothy grass | *Phleum pratense* |
| Perennial Rye grass | *Lolium perenne* |
| Italian Rye grass | *Lolium italicum* |
| Smooth Meadow grass | *Poa pratensis* |

OTHER PLANTS OF THE J.A.G.S. MEADOW

| | |
|---|---|
| Red Clover | *Trifolium pratense* |
| White Clover | *Trifolium repens* |
| Alsike Clover | *Trifolium hybridum* |
| Dog Daisy | *Chrysanthemum Leucanthemum* |
| Meadow Buttercup | *Ranunculus acris* |
| Bulbous Buttercup | *Ranunculus bulbosus* |
| Sorrel | *Rumex acetosa* |
| Meadow Saxifrage | *Saxifraga granulata* |
| Burnet Saxifrage | *Pimpinella saxifraga* |
| Common Vetch | *Vicia sativa* |
| Lady's Smock | *Cardamine pratensis* |
| Wild Angelica | *Angelica sylvestris* |
| Sneezewort | *Achillea Ptarmica* |
| Yarrow | *Achillea Millefolium* |
| Lesser Stitchwort | *Stellaria graminea* |
| Chervil | *Anthriscus sylvestris* |
| Wild Carrot | *Daucus Carota* |
| Fleabane | *Pulicaria dysenterica* |
| Pignut | *Conopodium denundatum* |
| Salad Burnet | *Poterium Sanguisorba* |

[1] *Weeds of Farm Land*, Brenchley, 1920.

OTHER PLANTS OF THE J.A.G.S. MEADOW (*continued*)

| | |
|---|---|
| Cat's Ear | *Hypochaeris radicata* |
| Cowslip | *Primula veris* |
| Mouse-ear Hawkweed | *Hieracium pilosella* |
| Ragged Robin | *Lychnis Flos-cuculi* |
| Hawkbit | *Leontodon hispidus* |
| Field Scabious | *Scabiosa arvensis* |
| Marsh Thistle | *Cirsium palustre* |
| Meadow Pea | *Lathyrus pratensis* |
| Knapweed | *Centaurea nigra* |
| Smooth Hawk's-beard | *Crepis virens* |
| Lady's Bedstraw | *Galium verum* |
| Great Burnet | *Sanguisorba officinalis* |
| Musk Mallow | *Malva moschata* |
| Thyme-leaved Speedwell | *Veronica serpyllifolia* |
| Early Purple Orchid | *Orchis mascula* |
| Spotted Orchid | *Orchis maculata* |
| *Yellow Rattle | *Rhinanthus Crista-galli* |
| *Red Rattle | *Pedicularis palustris* |
| *Eyebright | *Euphrasia officinalis* |
| *Viscid Bartsia | *Bartsia viscosa* |

* Not established.

## CHALK BEDS

In 1904 two small pieces of ground, each 12 ft. by 4 ft., were set aside for plants which usually grow on chalk and limestone soils. The top part of the garden soil was removed, and chalk soil from a district in Surrey was put in the beds. In 1928 four cubic yards of chalk soil were sent as a present from another part of Surrey, where excavations for road making were in progress, and another bed for chalk plants was made in the newer part of the botany gardens, after the garden soil had been dug out to a depth of 18 in.

PLANTS OF THE J.A.G.S. CHALK BEDS

| | |
|---|---|
| Baneberry | *Actaea spicata* |
| Beech | *Fagus sylvatica* |
| Bladder Campion | *Silene Cucubalus* |
| Box | *Buxus sempervirens* |
| Burnet Saxifrage | *Pimpinella saxifraga* |
| Columbine | *Aquilegia vulgaris* |
| Crested Hair-grass | *Koeleria cristata* |
| Cut-leaved Germander | *Teucrium Botrys* |
| Dropwort | *Spiraea Filipendula* |

PLANTS OF THE J.A.G.S. CHALK BEDS (*continued*)

| | |
|---|---|
| Dwarf Thistle | *Cirsium acaule* |
| Eyebright | *Euphrasia officinalis* |
| Field Flea-wort | *Senecio integrifolius* (*campestris*) |
| Foetid Iris | *Iris foetidissima* |
| Glaucous Sedge | *Carex glauca* |
| Great Mullein | *Verbascum Thapsus* |
| Ground Pine | *Ajuga Chamaepitys* |
| Hare's Ear | *Bupleurum rotundifolium* |
| Hoary Plantain | *Plantago media* |
| Juniper | *Juniperus communis* |
| Lady's Bedstraw | *Galium verum* |
| Lady's Fingers | *Anthyllis Vulneraria* |
| Milkwort | *Polygala vulgaris* |
| Mouse-ear Chickweed | *Cerastium arvense* |
| Mouse-ear Hawkweed | *Hieracium pilosella* |
| Nettle-leaved Campanula | *Campanula Trachelium* |
| Orchids: Bee | *Ophrys apifera* |
| Fly | *Ophrys muscifera* |
| Man | *Aceras anthropophora* |
| Spider | *Ophrys aranifera* |
| Spotted | *Orchis maculata* |
| Pasque Flower | *Anemone Pulsatilla* |
| Privet | *Ligustrum vulgare* |
| Purging Flax | *Linum catharticum* |
| Rest Harrow | *Ononis spinosa* |
| Rock Rose | *Helianthemum vulgare* |
| Round-headed Rampion | *Phyteuma orbiculare* |
| Sainfoin | *Onobrychis viciaefolia* |
| Salad Burnet | *Poterium Sanguisorba* |
| Silver-weed | *Potentilla anserina* |
| Small Scabious | *Scabiosa columbaria* |
| Stinking Hellebore | *Helleborus foetidus* |
| Thyme | *Thymus Serpyllum* |
| Tufted Vetch | *Vicia Cracca* |
| Tway-blade | *Listera ovata* |
| Upright brome grass | *Bromus erectus* |
| White Helleborine | *Cephalanthera grandiflora* |
| Whitlow Grass | *Draba muralis* |
| Wild Mignonette | *Reseda lutea* |
| Yellow-wort | *Chlora perfoliata* |

### THE WALL

A short wall was built of large pieces of stone with soil in between them. Wall plants and their seeds were put in the soil. Some were difficult to establish and the wall did not compare

favourably with some old walls to which presumably the seed had been carried by wind or other agents.

After the wall in the botany gardens had been in existence several years it was pulled down and the plants and soil were put between the layers of stone as the wall was built. It was found that the plants were anchored more firmly.

PLANTS ON THE J.A.G.S. WALL

| | |
|---|---|
| Biting Stonecrop | *Sedum acre* |
| Black Spleenwort | *Asplenium Adiantum-nigrum* |
| Ivy-leaved Toadflax | *Linaria Cymbalaria* |
| Lanceolate Spleenwort | *Asplenium lanceolatum* |
| Maidenhair Spleenwort | *Asplenium Trichomanes* |
| Pellitory-of-the-Wall | *Parietaria officinalis* |
| Red Valerian | *Centranthus ruber* |
| Shining Crane's-bill | *Geranium lucidum* |
| Scaly Fern | *Ceterach officinarum* |
| Snapdragon | *Antirrhinum majus* |
| Wallflower | *Cheiranthus Cheiri* |
| Wall Pennywort | *Cotyledon Umbilicus* |
| Wall-Rue Spleenwort | *Asplenium Ruta-muraria* |

VARIATION

1. As an introduction to the study of variation, collections were made of leaves from one individual plant. Leaves from a mulberry-tree showed considerable variation in their shape. They were pressed and mounted, and kept for reference.

2. The lengths of 100 haricot bean seeds were measured. The results were then shown in a graph, and the actual bean seeds were mounted in vertical rows on black cardboard, thus illustrating the variation pictorially.

3. The ray florets of hundreds of common daisies were counted. One year the number varied from 20 to 57 in a head, and by plotting a curve the variation was graphically represented. The experiment was repeated each year for years, and the results combined, a new curve with a more smooth outline being obtained with apparently two modes.

4. Graphs showing variation in the number of rays in umbels of hedge parsley were also made.

STRUGGLE FOR EXISTENCE

1. One hundred and seventy-five acorns were planted in November 1922 outside the wood, in a small plot 23 ft. 10 in.

by 6 ft. 4 in. A great number germinated. At Professor Tansley's suggestion they were left 'to fight it out', and show the survival of the fittest.

| | | |
|---|---|---|
| In 1922 | 178 | acorns planted. |
| „ 1926 | 133 | oak trees. |
| „ 1929 | 125 | „ „ |
| „ 1931 | 122 | „ „ |
| „ 1932 | 98 | „ „ |
| „ 1933 | 86 | „ „ |

2. A map has been made of the vegetation in a plot 15 ft. square in the wood, and a study is being made of the struggle for existence between dog's mercury and bluebells.

### MENDELIAN EXPERIMENTS

All the experiments at J.A.G.S. to investigate Mendel's Laws of Inheritance were made by girls of post-matriculation stage.

**1. 1st year.** Crosses were made between pea plants grown from seeds having yellow cotyledons and plants grown from seeds having green cotyledons.

Seeds were obtained as a result of the crossing which on examination were all found to have yellow cotyledons.[1] Thus yellowness was a dominant character. These seeds were kept to continue the experiments the following year.

**2nd year.** The seeds were sown and the resulting plants all yielded seeds, some of which had yellow and some green cotyledons.

The numerical results were as follows:

637 seeds with yellow cotyledons, 215 with green, or a ratio of 3 : 1·01. According to Mendelian laws the ratio should be 3 : 1. The experimental result thus shows a very close approximation to the theoretical. Expressed in a table:

Yellow cotyledons × Green cotyledons

$F_1$ Generation. Yellow cotyledons

$F_2$ Generation. Yellow Yellow Yellow Green

[1] It is necessary to chip each seed to ascertain the colour of the cotyledons.

**2.** Further experiments were made with pea seeds kindly sent from the John Innes Horticultural Institution. The sincere thanks of the J.A.G.S. Botany Department are also due to this institution for help and advice as to methods of procedure.

**1st year.** Crosses were made between pea plants differing in the following characters:

| SET A | SET B |
|---|---|
| Acacia leaves (no tendrils). | Normal leaves with tendrils. |
| Normal stems. | Fasciated stems. |
| Emerald (non-glaucous), chiefly stipules and pods. | Glaucous. |
| White flowers. | Purple flowers. |
| Green pods. | Purple pods. |

**Method of procedure.** Fingers and forceps, which had been sterilized in alcohol, were used for turning back the wings and keel of a bud of a plant in Set A, and for plucking out the stamens. Care had to be taken that the stamens were still unripe.

After the removal of the stamens the wings and keel were released and again enclosed the pistil. A small square of muslin was then folded in half over the bud and pinned, and a small label bearing the plant's number was attached to the stalk of the bud.

(Every plant was given a registration number, such as $\frac{8}{80}$ or $\frac{5}{81}$, the denominator indicating the year.)

After twenty-four hours the muslin was removed, the wings and keel were again turned back, and the exposed style was pushed into the inverted keel of a flower which had just been picked from a plant of Set B. During the operation of turning back the wings and keel, this flower was held by its stalk in the mouth of the experimenter in order to set both hands free. Holding the flower in an inverted position during the process of pollinating facilitated the entrance of the style of the bud into the keel of the flower. The pollinated bud was then re-pinned in muslin and the number of the plant supplying the pollen added to the label. The muslin was removed when the pod began to form.

The seeds obtained as a result of these crosses were harvested.

**2nd year.** The above seeds were sown and all yielded $F_1$ (first filial generation) plants showing the dominant characters of the pairs of characters under consideration.

$F_1$ Generation.

Normal leaves
Normal stems
Glaucous
Purple flowers
Purple pods

**3rd year.** The seeds of the $F_1$ plants were sown and the $F_2$ plants examined for the characters set out above.

$F_2$ Generation.

| | *School result* | *Theoretical result* | |
|---|---|---|---|
| Normal leaves *v.* Acacia | 96 : 29 | 93 : 31 | 3 : 1 |
| Normal stems *v.* Fasciated | 89 : 36 | 93 : 31 | 3 : 1 |
| Glaucous *v.* Emerald | 94 : 31 | 93 : 31 | 3 : 1 |
| Purple flowers *v.* White | 92 : 30 | 91·5 : 30·5 | 3 : 1 |
| Purple pods *v.* Green | 67 : 57 | 72 : 56 | 9 : 7 |

**3.** Red snapdragons were crossed with white, and the flowers of the plants of the resulting $F_1$ generation were all an intermediate shade. Parents and offspring plants were on view in plots.

The $F_2$ generation yielded a variety of colour forms: 5 different red types could be distinguished and 2 white or yellow. Of 63 plants examined the ratio of those showing red colour to those without it was 46 : 17. (The 3 : 1 ratio is approximately 47 : 16.)

### SOIL EXPERIMENTS

Some bacteria of the soil which enter the root-hairs of many of the plants of the family *Leguminosae* and other plants are able to use the free nitrogen of the air and make nitrogen compounds. They form swellings on the roots, the root tubercles. Some of the bacterial cells of the tubercles are digested by the plant, which thus obtains an extra supply of nitrogen.

Lupin plants were grown in a plot at J.A.G.S. from 1901 to 1909 and good specimens were obtained of tubercles on roots. A crop of lupin plants improves poor soils. It increases

the supply of available nitrogen. In 1906 experiments were made on two adjacent plots of sweet pea plants. One was watered with ordinary water, and one with a bacterial culture solution, the material for which was kindly supplied by King's College, London. Not much difference was seen in the development of the plants, and Professor Bottomley thought that plants growing in poorer soil would have shown a greater difference. In the farming of poor soils inoculation with the bacteria which form root tubercles has been found advantageous.

**Effect of absence of manure.** Wheat was grown in the same two plots from 1901 to 1909, year after year, without any manure being given. The same number of grains were sown each year, and the crops watched and gathered. It was intended that this experiment should go on for many years like the famous experiment at Rothamsted, but the ground was needed for the making of a lane in 1909, and the experiment was stopped. The later crops of wheat were certainly not so good as the early ones.

MANURIAL EXPERIMENTS

**1. Water-cultures.** The growth of plants in normal food solutions and in solutions lacking one of the following elements: phosphorus, nitrogen, magnesium, calcium, sulphur, iron, or potassium, may be said to be of the nature of manurial experiments. (See Chap. III.)

**2. Influence of nitrates on leaf development.** Small Brussels sprout plants were grown from seed in large pots. One pot contained ordinary garden soil, the other, soil supplied with extra nitrate. There was much greater leaf development in the plants supplied with extra nitrate.

**3. Field experiments. Effects of artificial manures.** The soil in a piece of ground approximately 23 ft. by 18 ft. was dug over and limed, and the ground divided into five plots. Mustard seed was sown thinly in rows 9 in. apart, three rows in each plot. The plants were thinned at intervals until they were from 4 to 6 in. apart. In the first year of the experiment, when the plants were well above the ground, chemical manures were

spread over the surface of the ground between the rows in four of the plots, but in succeeding years the manures were applied to the soil before the crop was sown. The following chemical manures were used:

Plot 1. No manure.

Plot 2. Complete manure.
5 oz. superphosphate.
2½ oz. sulphate of ammonia.
3 oz. sulphate of potash.

Plot 3. Manure lacking potash.
5 oz. superphosphate.
2½ oz. sulphate of ammonia.

Plot 4. Manure lacking phosphate.
2½ oz. sulphate of ammonia.
3 oz. sulphate of potash.

Plot 5. Manure lacking nitrogen.
5 oz. superphosphate.
3 oz. sulphate of potash.

Sulphate of potash was used instead of kainit as it is a suitable manure for spring application, and kainit should be applied in the winter. Superphosphate was used instead of basic slag as it is more suitable for use in the spring.

**Appearance in the field.** The plants in soil supplied with complete manure were more vigorous than the plants in other plots, especially than those in the plot with no manure. The plants supplied with manure lacking nitrogen were poorer than those in the plots supplied with manure lacking phosphate or potash.

The crops of all five plots were harvested when the plants were in full flower, and the first fruits were developed but not ripened. The plants were cut off at ground-level. The green weight was taken in the field, compression balances being used. The crop from each plot was air-dried separately. There are no facilities for drying at 100° C. all the material from each plot, so two duplicate air-dried samples taken from each set were weighed, dried in a water-oven, and an average factor obtained.

If $x$ = constant air-dried weight of sample, and

$y$ = constant oven-dried weight of sample,

$v/x$ multiplied by the constant total weight of air-dried material from a plot gives the amount of dry matter in the plot.

The percentage of dry weight in the green weight can then be found. The results obtained from the plants of the five plots are summarized in tabular form.

| *Plot* | *Treat-ment* | *Green wt. of crop* | *Const. air-dried wt. of crop* | *Wt. of sample* $= x$ | *Const. oven-dried wt.* $= y$ | *Fraction* $\frac{y}{x}$ | *Percentage dry wt.* |
|---|---|---|---|---|---|---|---|

Fresh crops have been sown, and the experiments are still being carried on. It is hoped that a number of results will be recorded from which conclusions may be drawn.

Thanks are due to Dr. Brenchley of the Rothamsted Experimental Station for the help and advice given when the experiments were begun and during their progress.

## XIV

## THE WOODS

A SMALL wood was made in 1909. No school money was available. Some of the trees were given by girls when they left school to commemorate their school life, especially their connexion with the botany gardens. Mistress and girls obtained plants for the ground vegetation. The wood was of great use in those early days, but it was too small, and did not represent any type of English wood.

When the Governors acquired a large field, a piece of ground, about a quarter of an acre in extent, was set aside for the new wood. The plot was in the shape of an irregular four-sided figure. The ends measured 102 ft. and 45 ft., the sides 153 ft. and 164 ft.

The ground was trenched three spits deep in 1914, care being taken that the soil was replaced at its original level, the subsoil not being brought to the surface.

**Type of wood.** The fact that the soil at Dulwich is clay, and also that the ground vegetation of a 'damp oakwood' is a most attractive one, led to the decision that the wood should be of the type known as a damp oakwood, having *Quercus robur* (*Q. pedunculata*) as the dominant tree. It was decided that a small part of the wood should be planted with ash trees, and that a deep hollow should be made for damp-loving herbaceous plants, and the hollow surrounded by willows.

A border 6 ft. wide was to be left on three sides of the wood, and typical woodland shrubs and small trees planted in it.

**Oak Trees.** Reference to many authorities was made before the size of the trees to be planted was settled. Some advised oaks 2 to 2½ ft. high, others 3 to 5 ft., 4 to 6 ft., and even second-year seedlings. Finally 2 to 3 ft. was the height chosen.

Hard woods, such as oak and ash, are usually planted some distance apart, and the spaces between the trees filled in with Scotch fir, or spruce, or larch, to act as 'nurses' to be removed as the oak and ash trees grow. It was felt that the 'nurses' might live and not the oaks, so it was decided that the oak trees were

to be placed very close to each other, only 3 ft. apart, in order to obtain a canopy as soon as possible, and to enable the leaders to run up 'straight and clean', and as the trees grew some of the least promising were to be removed.

Estimates were obtained from six well-known forest tree growers, and then by request samples were sent by two of the firms and the choice was made.

**Ash trees.** Ash trees were planted in the wood in order that the ground vegetation under them could be compared with that under the oak trees, as the plants became established. The trees when planted were 5 to 6 ft. in height.

**Willows.** The firm that supplied the oak trees sent willow cuttings to ensure an equal number of staminate and pistillate trees, but these were so unsightly that only a few were used, and these did not live. In 1915 twenty-five young goat-willow trees, 4 to 5 ft. high, were planted. Unfortunately, as was seen later, there were many more pistillate than staminate. The willows have been so popular with the bees that in the spring a loud humming noise has often been heard on entering the wood.

**Planting of oak and ash trees.** It was considered advisable that the firm that supplied the trees should send a planter. He came on December 21st, 1914, and in little more than two short days (the sun set before 4 o'clock) he planted 783 oaks and 61 ash trees, 3 ft. apart in all directions. All the trees lived.

The cost of the 844 trees plus the planting was £8 16*s*. 6*d*.[1]

**The border.** In the spring of 1915, 200 bramble plants were put in the border on three sides of the wood. In the autumn many shrubs and small trees were added: hazel, hawthorn, sloe, spindle, crab-apple, gean, maple, honeysuckle, wild rose, and others. The cost of 244 shrubs and small trees for the border was £2 16*s*.

[1] Prices of trees, autumn 1933:

| | |
|---|---|
| Oaks . . . . | 2 to 3 ft., 17*s*. 6*d*. and 21*s*. per 100. |
| Ash . . . . . | 3 to 4 ft., 15*s*. per 100. |
| Bramble plants . . | 15*s*. per 100. |

**The ground flora.** Primroses, bluebells, wood anemones, and campions were put in the wood in 1915 soon after the oak and ash trees were planted. Every year more plants were added to the ground flora, and many of those already in the wood gave rise to others, some by seeds, some by vegetative reproduction. In 1919 there were thousands of bluebell plants, 550 primrose plants, 500 dog's mercury, 350 lesser celandine, 300 wood anemones, as well as yellow dead-nettles, early purple orchids, tway-blades, and other plants. At the time of writing there are many more—in some cases, thousands—of these plants, also those of other genera and species.

We were fortunate in hearing through one of H.M. Inspectors that a road was being cut through a wood on the outskirts of London, and that great numbers of bluebell bulbs were being dug up and thrown away.

Girls from several forms made expeditions to the wood in their holidays, and nearly 3,000 bluebell bulbs were brought back and put in the J.A.G.S. wood.

The wood is beautiful in the spring with the unfolding leaves, a deep blue haze of bluebells, and hundreds of primroses and campions in the carpet of dog's mercury plants.

### COMPETITION OF WOODLAND PLANTS AND WEEDS

Before the oak and ash trees grew and afforded shade the ground vegetation had a great struggle with grass and other plants, and many 'aliens' had to be removed. The most rampant weeds in the wood soon after the trees were planted were grass, clover, groundsel, coltsfoot, and creeping buttercup. In 1916 they had increased so much that girls volunteered to come in the holidays and remove them, and some clearance of weeds was effected.

The excessive growth of meadow grass among the ground flora was overcome by time. When the trees had grown sufficiently to afford a close canopy the grass did not survive. A year after the trees were planted thousands of groundsel plants flourished, but were exterminated in 1916. Coltsfoot was difficult to eradicate. The flower heads were cut off as soon as they appeared to prevent fruit being formed. In March 1918, 3,105 coltsfoot plants were dug up, and the wood was soon free from them.

Creeping buttercup was by far the worst 'alien', and at one time it seemed as if it would be the conqueror. When the ground was trenched, and when the oaks were planted, not one buttercup plant was seen. In 1917, 7,865 plants were removed in May and July, but in 1918 the number had increased so enormously that a special effort had to be made so that the girls should not have to acknowledge themselves beaten by the plants. A 'buttercup week' was instituted, and girls throughout the school left work in their own gardens to help in the wood: 33,380 buttercup plants were removed in the week. The plants had multiplied by runners and by seed, but chiefly by runners. One plant was dug up with 30 young plants attached to it. In 1919, early in the year, 239,268 plants were removed, and the next year 162,227. The year 1920 saw the conquest of the buttercup. After 1923 it was difficult to obtain any plants wanted for class specimens. Nearly half a million plants had been removed by the girls in four years.

### AGE AT WHICH ACORNS ARE BORNE

When it was decided in 1914 that the wood should be of the damp oakwood type it was expected that it would be many years before any fruit would be formed. Marshall Ward gave 20 to 30, or even 80 years, before oaks would bear flowers. Another authority stated: 'The tree does not commence to bear good fruit until the ripe age of 60 or 80 years.'

In September 1918 eleven acorns were found, some on the ground, some on trees. On reference to the growers the age of the trees when planted in December 1914 was ascertained to have been from 3 to 4 years. The age at which fruit was borne on some trees was, therefore, 7 to 8 years. As this seemed abnormal a letter was sent to the Director of Kew Gardens stating the facts.

The Director, in reply, stated it was unusual for *Quercus pedunculata* to produce acorns when only seven or eight years old, but that Mr. Elwes in *Trees of Great Britain and Ireland*, says it 'begins to bear at a very early age in some cases'. In 1906 Mr. Elwes received a packet of acorns taken from trees ten years old. According to Dr. Hemsley in Hooker's *Icones Plantarum* several authors have mentioned the common oak as occasionally flowering in the seed beds. 'Trees do not produce

full masts until they are about 70 years old' (Schlich, *Manual of Forestry*).

Acorns were found at Dulwich in other years:

| | | |
|---|---|---|
| 15 in 1919 | 1,221 in 1924 | 4,618 in 1929 |
| 0 in 1920 | 510 in 1925 | 6 in 1930 |
| 43 in 1921 | 10 in 1926 | 466 in 1931 |
| 3,105 in 1922 | 132 in 1927 | |
| 0 in 1923 | 213 in 1928 | |

Marshall Ward pointed out that it was quite usual for a year with a heavy crop of fertile flowers to be followed by two or three years without flowers.

Seventeen years after the trees had been planted 10,350 acorns had been found. In most of these years there were probably more acorns formed than recorded, as when the girls returned in September there were many leaves on the ground, and acorns under and between leaves are not easily seen.

It was thought by some experts that the early age at which acorns were borne at J.A.G.S. was a bad sign for the future condition of the oak trees, but, in 1924, the tree expert from whom the trees had been bought visited the wood, pronounced it to be in good condition, and pointed out a number of very promising trees.

**Germination of acorns.** Some of the acorns produced in 1918 were sown in pots in February 1919 and did not germinate, but the non-germination might have been due to the acorns having been kept too long before they were planted, since it is known that acorns, if kept dry, soon lose the power of germination. Acorns of the 1919 crop were planted in December of the same year, and some did germinate. In the spring of 1921 a young oak seedling was found in the wood. In 1922, 175 acorns were planted and 133 germinated.

**Lammas shoots.** When trying to decide the age of the trees when fruit was first formed we were warned not to rely on bud scale scars, as the formation of Lammas shoots is quite frequent in *Quercus*. This led to an attempt being made to demonstrate the formation of these shoots. In the early part of 1919 pieces of red string were tied just below the terminal buds of branches

on forty oak trees, but in the late autumn it was found that no Lammas shoots had been formed on those branches. When this was repeated in 1922, however, Lammas shoots were found.

### BIRDS' NESTS

While the trees were very small no nests were seen, but when they had been planted a little more than five years a blackbird was seen on a nest in a willow tree near the dell.

Next year (1921) a hedge-sparrow built a nest low down in a bramble bush and four eggs appeared. Another hedge-sparrow built in the bramble, and two blackbirds in the hawthorns. The eggs in all four nests were hatched and the young birds flew away. A blackbird in the same year built in an oak tree.

1923 was a good year for nests. Three blackbirds nested in hawthorn bushes, four hedge-sparrows in brambles, and a thrush high up in an oak tree and three young thrushes were seen in the nest. (A blackbird also nested in the lane.)

It is now quite a usual thing for birds to build in the wood. Intense interest is shown by the girls, indeed at times the interest is almost too great, but the nests are not examined until they are deserted.

The wood affords a good opportunity for the study of bird life: identification of the bird inhabitants by their calls, their songs, and their appearance.

### THINNING OF THE WOOD

The oak trees planted at the end of 1914 grew well, and in 1919 had made such thick growth that advice as regards thinning was sought from the grower. He replied: 'You must be careful not to thin oaks too soon. It is most important that the boughs should shade the ground; also you require tall, clean stems, which are only procured by close growth. . . . To sum up: You may gradually thin, but it is most important to maintain canopy always.'

A tree expert in charge of some parks came to see the wood. He also emphasized the necessity of a canopy and straight leaders, and did not advise thinning. He was so interested in the wood that he would accept no fee!

In 1922 the head of the firm who had supplied the trees visited

the wood. He advised that 150–200 oak trees should be removed, including all those that had lost their leaders. In the summer and autumn 200 oak trees were removed and 2 ash trees.

In 1924, 35 oak trees were taken out, the lowest branches of all oaks 'thinned off', and several willows removed. More light was admitted into the wood by cutting back the hawthorns, hazels, and maples of the shrub border.

In 1926 advice was given that all rival leaders in the oaks should be pruned, that ash trees badly attacked by scale insect should be taken out, and others affected by it should be scrubbed with strong soft-soap solution. In this year 52 oaks, 1 willow, and 7 ash trees were removed. In 1931 there was a good report on the condition of the oak and ash trees—the willows were dying out owing to oak and ash trees growing up round them and cutting off the light supply. Fifty-six oak trees were cut down.

NUMBER OF TREES IN THE WOOD

| *1914 December* | *1931 September* |
|---|---|
| 783 Oaks | 298 Oaks |
| 61 Ash | 53 Ash |
| 25 Willows | 13 Willows |

PLANT DISEASES IN TREES OF J.A.G.S. WOOD

1. The oaks in 1924 were attacked by a fungus which formed white spots on the leaves and caused them to shrivel and turn brown. The fungus was identified at the British Museum (Natural History Department) as *Oidium alphitoides*, an oak mildew. It first appeared in Europe about 1906 or 1907, and rapidly spread.

2. The ash trees were attacked by a scale insect, the 'ash coccus'.

CHANGING CONDITIONS IN THE WOOD

The gradual change in the condition of the wood and its increase in distinctively woodland conditions have been most interesting to study and record.

As the young trees grew and developed more leaves, experiments were made to investigate the gradual changes in the conditions to which the ground vegetation was subjected. The experiments dealt with:

1. The soil. The humus content.

2. The atmosphere.
   (*a*) The temperature of the air inside the wood compared with that outside.
   (*b*) The total evaporating power of the air.
3. The light intensity to which the ground vegetation was subjected.

**1. Humus content of soil.**

The soil of the field where the new wood was made was poor in humus, and for some years when the trees were very young not many leaves enriched it. When the wood had been made eight years the percentage of humus in the soil from a part outside the dell was only 7·94, in 1929 it was 9·1, and in 1931, 10·2.

But the soil in the dell (the hollow surrounded by willows) is richer in humus than other parts. The trees are closer, the leaves on the ground are rarely disturbed, and the percentage of humus increased more rapidly. In 1925 it was 15·9, in 1929, 18·2, and in 1931, 20.

Twenty-six experiments have been made in various years to find the humus content of the soil outside the dell and seventeen to find that of the soil inside the dell. In every year in which records have been kept but one, the percentage of humus was practically twice as great in the soil inside the dell as in that outside.

The percentage of humus in some soil brought from a wood in Kent was found to be 24·25—the average result of ten experiments.

**2. The atmosphere.**

(*a*) **Comparison of temperature inside and outside the wood.** Maximum and minimum thermometers were placed inside the old wood and the new wood and outside each wood in the open, in the year 1917–18. The readings were taken about the same time, 11 a.m. in the mid-morning recess.

**New wood.** Two hundred and eighty-one readings were taken of the maximum and minimum temperatures of the air inside the wood and outside it during a period of five years. On more than half the number of days the maximum temperature inside the wood was less than that outside. When the readings were

first taken the trees were very young. In the first year of temperature records the maximum temperature inside was less than that outside on 47 days only out of 152 (30·9 per cent.), and the minimum temperature of the air inside the wood more than that outside on only 46 days (30·3 per cent.).

In 1920 when the trees had developed more leaves the maximum temperature inside was less than that outside on every day the observations were made, and the minimum temperature more than that outside on 78·6 per cent. of the days.

**Old wood.** In a total of 138 observations made during a period of three years the maximum temperature in the wood was lower than that outside on 119 days (86·2 per cent.) and the minimum temperature was higher on 93 days (67·4 per cent.).

It should be recorded that the trees of this wood are older and have a denser canopy than those of the new wood, also that in the old wood, 122 of the 138 observations were made after May 1st when the leaves had opened. In the new wood the observations were made throughout the year.

(*b*) **Comparison of total evaporating power of atmosphere inside and outside the wood.** For these experiments Livingston's porous cup atmometers are used, the non-absorbent form in order to avoid errors due to rainfall.[1] There was great difficulty in obtaining a supply of porous cups from America during the War, and it was not until July 1919 that one atmometer was placed in the middle of the wood and one outside. Two sets of observations are made. The girls in Form VI who are specializing in science usually make these experiments. The total number of comparisons between the evaporating power of the air inside the wood and the air outside in eleven years has been 92. In every case the quantity of water evaporated from the atmometer outside the wood has been greater than the quantity evaporated from the one inside in the same period.

The observations are usually made in the summer term. In the two years in which readings were taken in March, the difference in the volumes evaporated inside and outside the wood in that month was less during equal periods than in June, with the exception of one day.

[1] Livingston, *The Plant World*, 1915.

**3. Light intensities in the wood.**

In making these experiments the Wiesner photometric method has been adopted and an exposure meter used. The time taken for a piece of sensitized paper to acquire the standard tint is observed in:

1. Bright diffuse light at the beginning of the experiment.
2. Bright diffuse light at the end of the experiment.
3. The wood (*a*) under the oaks; (*b*) under the ash trees; (*c*) under the willows.

The observations are made as soon after mid-day as possible, generally at 12.30 (sun time). In each case the mean of three readings is taken. The average of the two results for bright diffuse light ($x$) is compared with the results under the oaks or ash or willows ($y$). The light intensity is in inverse ratio to the time taken for the paper to acquire the standard tint.

The ratios may be expressed either, as Wiesner expresses them, as the light intensity (at time of observation) under the trees as a fraction of that in the open $\left(\frac{x}{y}\right)$, or, as Salisbury expresses them, as the light intensity under the trees as a percentage of the light outside the wood, $\left(\frac{x}{y} \times 100\right)$, e.g. if the photographic paper takes 2 seconds under the trees and 1 second outside to reach the standard tint, it may be expressed as ½ or 50 per cent.

The experiments to find the intensity of light under the trees in the J.A.G.S. wood have extended over a period of thirteen years. They have been made by girls in the dinner-hour. As a rule there are no records in April owing to the Easter holidays. The observations in the wood have been made from the same places under oaks, willows, and ash trees.

1919. COMPARISON OF LIGHT INTENSITIES UNDER OAKS AND WILLOWS AND LIGHT INTENSITY OUTSIDE THE WOOD

| *Date* | *Time* | *Under Oaks* | *Under Willows* |
|---|---|---|---|
| May 21 | 12.30 (sun time) | 50 per cent. | 27 per cent. |
| ,, 30 | ,, ,, | 40 ,, | 14 ,, |
| June 6 | ,, ,, | 39·7 ,, | 13 ,, |
| July 31 | 10.30 ,, | 28 ,, | 11 ,, |
| Oct. 7 | 12.15 ,, | 33·3 ,, | 16 ,, |
| ,, 28 | ,, ,, | 50 ,, | 14 ,, |
| Nov. 25 | ,, ,, | 63·6 ,, | 58 ,, |



(*Photo H Drake*)

FIG. 34. The Dell and Atmometer. 1919. Label showing place where light intensity was noted under Willows

1926. COMPARISON OF LIGHT INTENSITIES UNDER ASH TREES AND LIGHT INTENSITY OUTSIDE THE WOOD

| *Date* | *Time* | *Percentage* |
|---|---|---|
| May 6 | 12.30 (sun time) | 70·8 |
| ,, 11 | ,, ,, | 60 |
| ,, 13 | ,, ,, | 58·3 |
| ,, 27 | ,, ,, | 25 |
| ,, 28 | ,, ,, | 25 |
| June 10 | ,, ,, | 21·4 |
| ,, 11 | ,, ,, | 18·2 |
| ,, 21 | ,, ,, | 15 |
| ,, 22 | ,, ,, | 8·75 |

LIGHT INTENSITIES UNDER OAKS IN VARIOUS YEARS SHOWING THE DECREASE WITH INCREASING THICKNESS OF CANOPY

| *Year* | *Dates* | *Average light intensities inside wood shown as percentages of light intensities outside wood at the same time* |
|---|---|---|
| 1921 | June 7, 13, 28 | 21·4 |
| 1926 | June 10, 11, 21, 22 | 11·1 |
| 1931 | June 2, 8, 15, 22 | 6·97 |

The above years have been chosen as owing to the range of dates on which the readings were taken a fair average for the month could be calculated.

LIGHT IN THE WOOD AS PERCENTAGES OF LIGHT IN THE OPEN IN LIGHT PHASE AND SHADE PHASE

| *Year* | *Date* | *Locality in wood* | *Percentage of light outside wood* |
|---|---|---|---|
| 1926 | March 26 (light phase) | Under willow trees | 61·7 |
| ,, | June 21 (shade phase) | ,, ,, ,, | 7·7[1] |

[1] The shade phase has probably not reached its maximum, compare the July record on p. 128.

**Simple light intensity experiments made by younger girls.** The experiments described above have been made by girls of Form VI, specializing in science, but in recent years the children of the two forms who had charge of the wood (average age, 12) made their own light intensity experiments with pieces of photographic paper.

The girls stood out in the open, or in various parts of the wood,

some under oak trees, others under ash trees. At a given signal (a whistle was blown) the pieces of photographic paper were produced from books, and exposed at arm's length. At another signal the papers were covered, brought into the laboratory, and fixed in hypo.

Some striking series were obtained, the paper from the open almost black, that from under the oaks very pale, and a medium tint under the ash trees.

### PLANTS OF THE NEW WOOD AT J.A.G.S.

TREES OF THE MAIN PART.

| | | |
|---|---|---|
| Common or Pedunculate Oak | *Quercus robur* (*pedunculata*) | (*d*)[1] |
| Ash | *Fraxinus excelsior* | (*l.sd.*) |
| Goat Willow | *Salix caprea* | (*f*) |

SHRUBS AND SMALL TREES.

| | | |
|---|---|---|
| Bramble | *Rubus fruticosus* | (*d*) |
| Common Hazel | *Corylus Avellana* | (*a*) |
| Wild Rose | *Rosa canina* and *arvensis* | (*a*) |
| Hawthorn | *Crataegus Oxyacantha* | (*a*) |
| Honeysuckle | *Lonicera Periclymenum* | (*a*) |
| Ivy | *Hedera Helix* | (*a*) |
| Maple | *Acer campestre* | (*f*) |
| Dogwood | *Cornus sanguinea* | (*f*) |
| Spindle | *Euonymus europaeus* | (*f*) |
| Guelder Rose | *Viburnum Opulus* | (*o*) |
| Gean | *Prunus avium* | (*o*) |
| Crab Apple | *Pyrus Malus* | (*o*) |
| Wild Service Tree | *Pyrus torminalis* | (*o*) |
| Wayfaring Tree | *Viburnum Lantana* | (*o*) |
| Common Birch | *Betula alba* | (*o*) |
| Hairy Birch | *Betula pubescens* | (*o*) |
| Sloe | *Prunus spinosa* | (*o*) |
| Hornbeam | *Carpinus Betulus* | (*r*) |
| White Beam Tree | *Pyrus Aria* | (*r*) |

HERBS.

| | | |
|---|---|---|
| Bluebell | *Scilla non-scripta* | (*l.d.*) |
| Dog's Mercury | *Mercurialis perennis* | (*l.sd.*) |
| Yellow Dead-nettle | *Lamium Galeobdolon* | (*l.sd.*) |
| Primrose | *Primula vulgaris* | (*a*) |
| Lesser Celandine | *Ranunculus Ficaria* | (*a*) |

[1] Symbols as in Tansley's *Types of Vegetation*: (*d*) = dominant; (*l.sd.*) = locally subdominant; (*f*) = frequent; (*o*) = occasional; (*r*) = rare; (*a*) = abundant; (*l.d.*) = locally dominant.



(*Photo R A Malby & Co*)

FIG. 35. Undergrowth in damp Oakwood (*Quercus robur*)

PLANTS OF THE NEW WOOD AT J.A.G.S. (*continued*)

HERBS (*continued*).

| | | |
|---|---|---|
| Wood Anemone | *Anemone nemorosa* | (*a*) |
| Enchanter's Nightshade | *Circaea lutetiana* | (*a*) |
| Pink Campion | *Lychnis diurna* (*Melandrium rubrum*) | (*a*) |
| Cuckoo-flower or Lady's Smock | *Cardamine pratensis* | (*a*) |
| Common Speedwell | *Veronica officinalis* | (*a*) |
| Germander Speedwell | *Veronica chamaedrys* | (*a*) |
| Hairy Wood Rush | *Luzula pilosa* | (*a*) |
| Bush Vetch | *Vicia sepium* | (*a*) |
| Wild Strawberry | *Fragaria vesca* | (*f*) |
| Bugle | *Ajuga reptans* | (*f*) |
| Greater Stitchwort | *Stellaria Holostea* | (*f*) |
| Herb Bennet | *Geum urbanum* | (*f*) |
| Wild Garlic | *Allium ursinum* | (*f*) |
| Wood Sage | *Teucrium Scorodonia* | (*f*) |
| Barren Strawberry | *Potentilla Fragariastrum* | (*f*) |
| Wood Violet | *Viola Riviniana* | (*f*) |
| Wild Arum | *Arum maculatum* | (*f*) |
| Ground Ivy | *Nepeta Glechoma* | (*f*) |
| Wild Angelica | *Angelica sylvestris* | (*f*) |
| Wood Sanicle | *Sanicula europaea* | (*f*) |
| Wood Sorrel | *Oxalis Acetosella* | (*f*) |
| Wood Spurge | *Euphorbia amygdaloides* | (*o*) |
| Wood Buttercup | *Ranunculus auricomus* | (*o*) |
| Figwort | *Scrophularia aquatica* | (*o*) |
| Woodruff | *Asperula odorata* | (*o*) |
| Tway-blade | *Listera ovata* | (*o*) |
| Foxglove | *Digitalis purpurea* | (*o*) |
| Wood Pimpernel | *Lysimachia nemorum* | (*o*) |
| Forget-me-not | *Myosotis sylvatica* | (*o*) |
| Lady Fern | *Athyrium Filix-foemina* | (*o*) |
| Hard Fern | *Blechnum Spicant* | (*o*) |
| Polypody | *Polypodium vulgare* | (*o*) |
| Oak Fern | *Polypodium* (*Phegopteris*) *Dryopteris* | (*o*) |
| Bracken | *Pteris aquilina* | (*o*) |
| Green Hellebore | *Helleborus viridus* | (*o*) |
| Early Purple Orchid | *Orchis mascula* | (*o*) |
| Spotted Orchid | *Orchis maculata* | (*o*) |
| Golden Saxifrage | *Chrysosplenium oppositifolium* | (*r*) |
| Lily-of-the-Valley | *Convallaria majalis* | (*r*) |
| Butcher's Broom | *Ruscus aculeatus* | (*r*) |
| Herb Paris | *Paris quadrifolia* | (*r*) |

# APPENDIX

**Percentage of water in plants.** For many years the percentage of water in plants, or parts of plants, has been found each year. Experiments are often made on leaves. The leaves have been obtained from the garden, dusted, weighed, and heated in a water-oven and weighed again. This heating has been repeated until the weight was constant. The percentage of water has been found in the leaves of forty-one genera. Usually a number of girls test leaves of the same plant, and the results are compared and recorded.

The percentage in leaves of different genera has varied from 60 to 89; in the great majority of leaves it was between 70 and 80. The percentages of water in whole plants, twigs, buds, bulbs, tubers, fruits, and seeds have also been found.

The percentages of water found in Brussels Sprouts in one year were 88·2, 88, 88, 88, 87·9, 87·8, 87·7, 87, 86·9, 85·9, 85·09—average 87·32; in the next year they were 87·04, 85·5, 85, 85, 84·7, 84·3, 84—average 85·08.

**Weight of ash.** After the leaves, or other parts of plants, had been dried they were strongly heated over a bunsen flame until no dark matter was left. Sometimes, as in the case of leaves, small baking tins (costing a penny each) were used instead of crucibles, as crucibles hold so little, and any error in weighing such small quantities would be larger in proportion. Sometimes crucibles were used for other parts than leaves, and occasionally the oven-dried portions of plants were heated strongly in hard glass test-tubes.

In all cases the ash formed was weighed, and heated again until the weight was constant. In a great many cases the weight of ash produced after the plants, or parts of plants, had been strongly heated was less than 3 per cent. of the original weight.

Weight of ash in potato tuber was 1·07 per cent. of original weight of tuber.
Weight of ash in maize grain was 1·2 per cent. of original weight of grain.

**Analysis of ash.**

**Test for sulphates.** If a solution of ash in water is filtered, the filtrate acidified with hydrochloric acid and barium chloride added, a white precipitate is formed, indicating the presence of sulphur in the form of a sulphate.

**Test for phosphates.** If an equal bulk of concentrated nitric acid is added to a *small* portion of ash solution, and then excess of ammo-

nium molybdate, a yellow precipitate, on boiling, indicates the presence of a phosphate.

**Test for sodium.** If a clean platinum wire, which has been dipped into hydrochloric acid, is put into some plant ash and then held in a non-luminous flame, a yellow colour indicates the presence of sodium.

**Test for potassium.** If a clean platinum wire, which has been dipped into hydrochloric acid, is put into some plant ash and then held in a non-luminous flame, and the flame viewed through blue cobalt glass, a reddish-violet coloration is seen, indicating the presence of potassium.

**Iodine solution.** Make a strong solution of potassium iodide in distilled water, and add to it crystals of iodine. Dilute this solution with distilled water to a light-brown colour.

**A deep sink.** A deep sink is a great convenience in a laboratory. In it potometers and other apparatus used in transpiration experiments can be fitted up under water. A tap well above the sink allows tall jars, such as those sometimes used in water-culture experiments, to be washed easily.

## TRANSPIRATION. READINGS OF POTOMETER UNDER VARYING CONDITIONS

The following readings were taken when a twig bearing twenty-seven leaves was inserted in a potometer (Farmer's).

| *External conditions* | *Distance in tube along which water receded* | *Time (in seconds)* | *Average* |
|---|---|---|---|
| Sunshine and breeze | 2 cm. | 10 | |
| | | 14 | |
| | | 12 | 12·4 |
| | | 13 | |
| | | 13 | |
| Shade and slight breeze | 2 cm. | 26 | |
| | | 30 | 30·6 |
| | | 36 | |
| No light | 2 cm. | 274 | |
| | | 212 | 221·3 |
| | | 178 | |

TO SEE IF THERE IS A RISE IN TEMPERATURE DURING RESPIRATION. WHEAT GRAINS

| *Date* | *Temperature of living grains* | *Temperature of dead grains* | *Difference* |
|---|---|---|---|
| | ° C. | ° C. | ° C. |
| Jan. 22 | 15·5 | 14 | 1·5 |
| „ 23 | 16 | 14·5 | 1·5 |
| „ 24 | 14·5 | 13 | 1·5 |
| „ 25 | 16 | 14 | 2 |
| „ 28 | 17·5 | 15 | 2·5 |
| „ 29 | 17·5 | 15 | 2·5 |

**Auxanometer.** A supply of sheets of paper the right size and gummed at one end can be obtained for the drum. The paper can be blackened by holding it in the smoky flame of a gas jet, but it is better to use the flame of burning camphor.

**Test for grape sugar (glucose).** Make a solution of grape sugar, and boil it in a test-tube with some Fehling's solution. A red precipitate is formed.

**Test for cane sugar if grape sugar is absent.** Boil a solution for a few minutes with dilute hydrochloric acid. (The cane sugar is changed into grape sugar.) Neutralize with caustic soda or potash. Add Fehling's solution and boil. A red precipitate is formed.

**Test for cane sugar if grape sugar is present.** Put equal quantities of the solution to be tested into two test-tubes of about equal diameters. (1) Add a measured volume of Fehling's solution to one test-tube and boil contents. (2) Add a little hydrochloric acid to the contents of the other test-tube, boil contents, and neutralize with caustic soda or potash. Add the same volume of Fehling's solution as in (1) and boil. If solutions in (1) and (2) are boiled for the same length of time after Fehling's solution is added, the amounts of precipitates can be compared and a roughly quantitative result obtained.

STORAGE OF FOOD IN PARTS OF PLANTS OTHER THAN SEEDS

| *Plants* | *Organ* | *Iodine test* | *Fehling's solution test* | *Nature of food* |
|---|---|---|---|---|
| Beetroot | Root | | Red ppt. | Grape sugar |
| Carrot | Root | Slight blue-black colour in small area | Red ppt. | A little starch<br>Grape sugar |
| Parsnip | Root | Blue-black colour | Red ppt. | Starch<br>Grape sugar |
| Turnip | Hypocotyl | Slight blue-black colour in small area | Red ppt. | A little starch<br>Grape sugar |
| Iris | Rhizome | Blue-black colour | Red ppt. | Starch<br>Grape sugar |
| Solomon's Seal | Rhizome | | Red ppt. | Grape sugar |
| *Apple | Receptacle | | Red ppt. | Grape sugar |
| *Grape | Pericarp of fruit | | Red ppt. | Grape sugar |
| *Tomato | Pericarp of fruit | | Red ppt. | Grape sugar |

Sugar is not a food reserve in these fruits.

# INDEX

Absorption of water,
by root, 4;
by moorland plants, 95;
by salt marsh plants, 102.
Acorns,
age of trees bearing, 122;
germination of, 113, 123.
Anaerobic respiration, 34.
Animal life,
in lane, 79;
in pond, 91;
in wood, 124.
Ash of plants,
analysis of, 16, 132;
weight of, 16, 132.
Atmometer, 127.
Auxanometer, 37–9, 134.

Bogs,
construction of, 83, 87, 96, 97;
plants of, 97, 98.

Carbon dioxide,
evolution of, 28–30;
and starch formation, 11.
Chalk beds,
construction of, 110;
plants of, 110, 111.
Chlorophyll and starch formation, 13.
Climbing plants, 71–4, 77, 78.
Clinostat, 43, 44, 47.
Cornfield, 107–8.
Culture solutions,
bacterial, 116;
water-, 16–21, 116.

Diastase, 4, 14.
Diseases,
of seedlings, 20;
of trees, 125.

Elements of plants, 16, 18.
Etiolated plants, 6, 7.
Evaporating power of the air, 127.

Flowering, time of, 78.
Food substances,
storage of, 3, 135;
tests for, 3, 134.
Freshwater marshes, 83;
plants of, 86, 87.

Germination, conditions of, 1–3.

Gravity, influence of,
on direction of growth, of root, 43;
of stem, 45, 46;
perception of, 44–6.
Growth,
distribution of, in root, 35, 36; in stem, 35, 37;
direction of, in root, 39, 40, 43; in stem, 40, 41, 46;
influence of light on, 5, 42;
measurement of, 37–9.

Heath,
construction of, 93;
plants of, 93–6.
Humus, 53, 106, 126.

Insects, observations of visits of, 65–70.
Iodine, solution of, 133.

Labels, 58.
Lammas shoots, 123.
Lane,
construction of, 75, 76;
plants of, 79–81.
Leaf structure, 24.
Light, influence of,
on germination, 2;
on growth of seedlings, 5;
on direction of growth, 40–2.
Light,
perception of, 42;
and starch formation, 10.
Light intensities, 128–30.

Manures,
effect of absence of, 116;
effect of artificial, 116–18.
Marshes, *see* freshwater marshes and salt marshes.
Meadow, 108–10.
Mechanical analysis of soil, 48.
Mendelian experiments, 113–15.
Microscope, use of, 23.
Moll's experiment, 12.
Mycorrhiza, 17, 93.

Nitrates, influence of, on leaf development, 116.

Oxygen,
absorption of, 30.
evolution of, 12, 13.

Paths,
round ponds, 83, 85;
plants of, 87, 88.
Peat bogs, *see* bogs.
Pebble beach,
construction of, 104–6;
plants of, 106.
Permeability of soils to air, 52.
Photosynthesis, 8–15.
Pollination,
experiments on, 60–5;
of primrose, 64.
Ponds,
construction of, 82–5;
plants of, 85, 86.
Pores in leaves, 23.
Potometer, 25–7, 133.

Reports on work, 58.
Reproduction,
of water plants, 88.
of sand dune plants, 100.
Respiration, 28–34, 134.
Respiratory coefficient, 31.
Respiroscope, 1.

Sachs' solution, 17.
Salt marshes, 101–4;
plants of, 87, 104.
Salt solution, 101, 103.
Sand dunes,
construction of, 99;
plants of, 101.
Self-pollination,
records of, 62;
in annuals, 63, 64.
Sink in laboratory, 26, 133.
Soil, experiments on, 48–54, 79, 115.
Starch,
conditions of formation of, 9, 10–14;
conversion into sugar of, 14;
records of, 3, 8, 9, 135.
Starch prints, 10, 11.
Stomates, 24;
of salt marsh plants, 102.
Struggle for existence, 112.
Sugar, presence of,
in leaves, 9;

Sugar, presence of (*contd.*)
in other parts, 135;
tests for, 134.

Tools, care of, 57.
Temperature,
and germination, 2;
and oxygen production, 13;
and respiration, 33, 134.
Temperatures,
in pond, 89–91;
of soil, 54, 79;
in woods, 126.
Transpiration,
demonstration of, 22 et seq.;
rate of, 25–8, 133;
of heath plants, 95;
of salt marsh plants, 101.
Transpiration and absorption, 27.

Variation, 112.
Visitors to gardens, 58.

Wall,
construction of, 111;
plants of, 112.
Water,
path in stem, 5;
influence on direction of growth, 39;
percentage in plants, 16, 132;
percentage in soil, 48;
of moorland soil, 95;
of salt marshes, 102;
rise of, in soil, 50–2.
Water capacity of soils, 52.
Water-cultures, 16–21, 116.
Water supply,
of bog, 97;
of ponds, 82, 83, 85;
of salt marshes, 101, 103.
Weeds, competition of,
in heath, 94;
in wood, 121.
Woods,
changing conditions of, 125–30;
construction of, 119–20;
ground flora of, 121;
plants of, 130, 131;
thinning of, 124.

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